

**INTERNATIONAL SUBCOMMISSION ON
STRATIGRAPHIC CLASSIFICATION (ISSC)**

OF

**IUGS INTERNATIONAL COMMISSION ON
STRATIGRAPHY**

CIRCULAR NO. 100

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I. SEQUENCE STRATIGRAPHY

As informed in ISSC Circular No. 99 (July 26, 2001) the WG on Sequence Stratigraphy agreed to recommend the abandonment of the allostratigraphic units and the synthems, but was not able to agree on a definition of sequence. Therefore, two different proposals were presented, which were reproduced as Appendix A and B to ISSC Circular No. 99.

Those views, and others, were discussed at a AAPG Hedberg Research Conference, titled "Sequence Stratigraphic and Allostratigraphic Principles and Concepts", held in the Ellison Miles Geotechnology Institute at Brookhaven College in Dallas, Texas, August 26 – 30, 2001.

The American Association of Petroleum Geologists, North American Commission on Stratigraphic Nomenclature (NACSN) and ISSC sponsored the Conference. It was designed to provide input into the deliberations of the ISSC and NACSN working groups on allostratigraphic and sequence stratigraphic units for possible amendment to the International Stratigraphic Guide and to the North American Stratigraphic Code.

A report by Maria Bianca Cita, ISSC Vice Chairman – "Highlights of the AAPG Hedberg Conference" is included as **Appendix A** to ISSC Circular No. 100.

Comments and suggestions concerning those documents and the general subject of unconformity related units were also requested from the members of the Subcommittee. As a result I received some comments from Ivo Chlupac (see below) and two documents from Henk de la R. Winter on "What is a sequence?" and "Time is running out", here included as **Appendix B** to ISSC Circular No. 100.

After the Hedberg Conference the Co-ordinator of the WG on Sequence Stratigraphy, Amos Salvador, has circulated Memo 22 (December 10, 2001). There, two options were proposed: 1) To agree to assign sequence stratigraphy an informal status for the time being, convey this recommendation to the ISSC, and deactivate the WG, 2) To not agree that sequence stratigraphy should be considered an informal methodology, and make one last attempt to reach an agreement on a set of recommendations to be submitted to the ISSC, that eventually can be published.

It is clear that the Hedberg Conference was not a decision-making body, and that the WG and ISSC are not compelled to follow its recommendations. As ISSC Chairman, I wrote to Amos Salvador that in reaching a decision concerning the next step for the WG "it is important to consider that the 'International' SSC was not created to leave stratigraphy informal'. Hedberg fought for years to arrive to a Guide that, in spite of relevant opponents, was accepted throughout the world. He knew that it is impossible to reach unanimous decisions, but he built a 'international' majority to support a viable and practical classification and that, the work of the WG "should not be spoiled and should be used to make a practical and viable proposal to the 'International' SSC".

Amos Salvador agrees, and in the WG Memo No. 22, he favored option 2 of those listed above.

Thus he is trying to reach an agreement within the WG in order to prepare a complete document that can be submitted to the ISSC.

Comments by Ivo Chlupac

My comments on Appendices A and B of the ISSC Circular No. 99 are as follows: I strongly prefer the statement in the Appendix A recognizing a single term "sequence" for unconformity-related units. I also agree that allostratigraphic units and synthems should be abandoned.

The bipartite meaning of sequence - the stratal and depositional ones, seems me less practical. It could cause difficulties in practical usage and in translations in other languages too.

II. CYCLOSTRATIGRAPHY

ISSC Circular No. 97 (July 10, 2000) included as App. B & C a Report and a Questionnaire, dealing with concepts, applications, terminology and operational problems of Cyclostratigraphy, prepared by Frits Hilgen, André Strasser and Walther Schwarzacher.

Responses to the Questionnaire as well as number of comments were included in ISSC Circulars No. 98 (October 27, 2000), No. 99 (July 26, 2001) and were circulated to the ISSC membership and to a number of other interested stratigraphers.

Since then the Working Group has produced a new document, here reproduced as **Appendix C** to ISSC Circular No. 100.

Comments and suggestions concerning this document and the general subject of Cyclostratigraphy would be appreciated from the members of the Subcommittee. In particular, expressions of opinion on the following specific points would be most helpful: 1) acceptance of Cyclostratigraphy as a formal stratigraphic category; 2) terminology to be used in cyclostratigraphy; 3) codification of cycles in cyclostratigraphy; 4) publication of the document by the ISSC WG.

III. ISC NEWS

NEW GSSP

Since distribution of ISSC Circular No. 99 the following GSSP was approved by ICS, and forwarded to IUGS for ratification:

- Base of Cenomanian, 36 meters below top of the Marnes Bleues Formation on the south side of the Mont Risou, east of Rosans, Haute-Alpes, France.

The following GSSP were submitted to the ICS for approval and are now being considered:

- Base of the "Second Stage" for the Ordovician System in the Diabasbrottet quarry, Hunneberg Mountain, province of Västergötland, Sweden.
- Base of the Upper Ordovician Series (and base of the "Fifth" Stage) in the Fagelsang section, east of Lund, Scane, Sweden.

ICS MEETING TO DEFINE FUTURE GOALS

As informed in ISSC Circular No. 99 the ICS Executive Committee is organizing a workshop of all chairs of ICS subcommittees to stimulate progress towards selection of GSSPs for all Phanerozoic stages by 2008 and to develop the future direction of the ICS. This meeting will be held at Urbino, Italy, on June 14 – 16, 2002. The Agenda of this "First Conference on Future Directions in Stratigraphy" was prepared by the appointed chairman Stan Finney, and is here included as **Appendix D** to ISSC Circular No. 100.

Any comments and suggestions from the ISSC membership to be taken to Urbino for discussion are welcome.

IV. PUBLICATIONS ON STRATIGRAPHIC CLASSIFICATION, ETC.

Following is a publication on stratigraphic matters kindly sent by Professor Zhamoida:

Zhamoida, A.I., 1999. Long and Laborious Way toward the Theoretical Stratigraphy. *Stratigraphy and Geological Correlation*, 7, 6: 611-620.

V. ISSC WEB SITE

The ISSC web site became available on-line from January 2002 at the following address http://www.geocities.com/issc_arg

It contains: information about the subcommittee, list of officers and members with addresses, admission of new members, Working Groups, list of publications with text of the last Circular, list of repositories of Circulars, links to related organizations. Text of previous circulars and memos of the WG on Sequence Stratigraphy will also be available in the future.

VI. MISCELLANEOUS

Lithuanian Stratigraphic Code

As informed in ISSC Circular No. 99, Professor A. Grigelis has requested circulation of his document "Lithuanian Stratigraphic Guide: newly introduced terms". It is here attached as **Appendix E** to ISSC Circular No. 100.

Errata to the "Resolution of the enlarge meeting of the Bureau of the Interdepartmental Stratigraphic Committee of Russia (ISC)"

Appendix D to ISSC Circular No. 99 included a "Resolution of the enlarge meeting of the Bureau of the Interdepartmental Stratigraphic Committee of Russia (ISC) concerning the International Stratigraphic Scale 2000". Now Prof. A.I. Zhamoïda, Head of the Interdepartmental Stratigraphic Committee of Russia and Russian representative to ISSC, has indicated a "disappointing misunderstanding in the paragraph 6 of Appendix D. It has to be written: 'To charge the ISC commissions on systems to liven up their work on preparation of materials on the international status of the stages of the Cambrian, the Carboniferous, the Permian and the Lower Triassic'".

On GSSPs

Professor Ivo Chlupac is asking "the members of ISSC for their views on the two following topics: In the article by Gehling and Jensen published in the Geological Magazine vol. 138, 2, p. 213-218 (2001) is a report on discovery of the ichnofossil *Treptichnus* (=former *Phycodes*) *pedum* below the Stratotype point within the Proterozoic-Paleozoic Boundary Stratotype at Fortune Head, Newfoundland. As just the first occurrence of this ichnofossil served as a marker of the boundary and a similar case of discovery of the boundary index below the Stratotype Point can happen practically in every stratotype of international chronostratigraphic units, the situation merits a wider attention from the practical viewpoint, namely:

- A. Is this discovery sufficient reason for a revision of the GSSP, particularly the Stratotype Point in the approved section?
- B. Should be the Stratotype Point in the approved stratotype moved into the new level of the first occurrence of the boundary index?
- C. Or – should the originally approved level of the Stratotype Point be left without any correction?

According to the Intern. Strat. Guide (1994, p. 91) and ICS Guidelines (1986) it is evident that ICS has its responsibility in the item. But what to do in praxis? Should be created a new Working Group and realize either the shift of the boundary level in the stratotype and, consequently, to loose the stability of the boundary level? Or should it leave the formerly approved boundary and to abandon the main boundary indicator and diminish the practicability of the boundary level for correlation?

A clear statement in this and similar cases would be very useful for practical application of the GSSP principle in cases which are inevitable marks for scientific progress".

**INTERNATIONAL SUBCOMMISSION ON STRATIGRAPHIC
CLASSIFICATION
APPENDIX A (TO ISSC CIRCULAR NO. 100)**

HIGHLIGHTS OF THE AAPG HEDBERG CONFERENCE
(DALLAS, TEXAS, AUG. 26-29, 2001)

(by MARIA BIANCA CITA, Department of Earth Sciences, University of Milan, Italy)

A research conference on “Sequence Stratigraphic and Allostratigraphic Principles and Concepts” hosted by

- the American Association of Petroleum Geologists (AAPG),
- the International Subcommittee on Stratigraphic Classification, of the International Commission on Stratigraphy (ISSC),
- the North American Commission on Stratigraphic Nomenclature (NACSN), and
- the Petroleum Technology Transfer Council

was held in Dallas, Texas, on August 26-29, 2001, at the Geotechnology Center of Brookhaven College.

The objective of the conference was to provide input into the deliberations of the International Subcommittee on Stratigraphical Classification and of the North American Commission on Stratigraphic Nomenclature on allostratigraphic and sequence stratigraphic units for possible amendment to the International Stratigraphic Guide and the North American Stratigraphic Code and to debate the merits of utilizing an integrated allostratigraphic and sequence stratigraphic approach to describe and interpret the stratigraphic record.

The conveners, and members of the program committee were:

- E. Mancini, from the University of Alabama,
- R. Jordan, Delaware Geological Survey,
- D.E. Owen, Lamar University,
- A. Salvador, University of Texas at Austin, and
- L.E. Edwards, U.S. Geological Survey.

The participation was limited in number (50) and by invitation only. The number and quality of participants was just perfect for such a focused research conference, and included at least three generations of geologists from universities and research centers, from big oil companies or smaller ones, from geological surveys or independent. Most conference participants were from the United States or Canada, but quite a few were from Europe, Central America and Asia.

During three full days some 30 presentations were given, most of them well presented, some really outstanding conceptually, and wonderfully documented. Indeed, the long time allocated to the presentations (40 minutes, including questions times) allowed a full development of a theme.

The papers were grouped in four well organized sessions:

1. Sequence stratigraphic principles, concepts and terminology;
2. Allostratigraphic principles, concepts and applications;
3. Application of sequence stratigraphy (basin scale);
4. Application of sequence stratigraphy (reservoir scale).

General discussion was held at the end of day one on sequence stratigraphic terminology (with Amos Salvador as discussion leader) and on application of sequence stratigraphy and allostratigraphy (with Janok Bhattacharya as discussion leader) at the end of day two.

The terminology issue was highly controversial. Amos Salvador, appointed six years ago by ISSC as coordinator of a large (too large?) working group on sequence stratigraphy, notwithstanding his strenuous efforts to keep together the group and to produce a final report, appeared not to have been able to reach a consensus on the definition of the simplest, basic unit, *the sequence*. Indeed, presentations given individually or jointly by several members of the ad-hoc working group at the conference (by, listed alphabetically, M.P. Aubry, W.A. Berggren, N. Christie Blick, D.E. Owen, H.W. Posamentier, A. Salvador, J.A. Van Couvering) showed the lack of a common language, and a large divergence of interpretations.

The best part of the conference was that on the examples, or applications of sequence stratigraphy at a basin scale. The case stories presented were extremely interesting, ranging:

- in age from the Devonian to the Holocene (including Mississippian, Pennsylvanian, Triassic, Jurassic, Cretaceous, Paleogene, Neogene);
- in areas from the Gulf Coast to the Arctic Islands, from the Niger Delta to the North Sea, from the Middle Interior to Spain, the Molasse Basin, Belgium, the Apennines, the Karroo Basin, New Mexico;
- in environment from fluvial to deltaic, to siliciclastic shallow marine, to deep marine, to carbonate platform, to carbonate ramp.

The Hedberg Research Conference offered a unique opportunity to compare observations and interpretations on land, at the outcrop scale, with basinwide 3D reconstructions based on subsurface data (high resolution seismic lines and well logs), and to point out points of agreement / vs. disagreement on the nature of sequence boundaries, of the relative importance of unconformable surfaces, on the relationships of these surfaces to “correlative conformities”, and on base-level versus sea-level as controlling factor of unconformable surfaces.

If sequence stratigraphy has been extremely successful in oil exploration for its predictive potential for sand bodies, leading to a new era of search for sedimentary traps, after the era of structural traps, if sequence stratigraphers often appear as “back riding the winning horse”, and short or special courses on the subject are given in all the major universities of the developed countries, the Hedberg Conference clearly showed how weak and controversial are some aspects of the conceptual model. I want to mention here in particular:

- the terrific logic of Ashton Embry on his six surfaces of sequence stratigraphy,
- the provocative talk of A.D. Donovan on the free-market theory of sequence stratigraphy and
- the keynote lecture by John Armentrout with all his critical evaluation of this “remote sensing” technique, from the original computer model to the application of various types of processing to the seismic lines, to the interpretation and correlation of well logs.

Among the best lectures presented by the defenders of allostratigraphy, I want to mention:

- the brilliant talk by Bhattacharya, a good example of clear thinking;
- the scholastic and aggressive, but sharp talk by Lucy Edwards, expressing the necessity of some formally defined allostratigraphic units for geological mapping;

- the unforgettable images, presented by John Holbrook, of cut-and-fill Cretaceous sandstones from the Middle Interior, interpreted in terms of architectural elements analysis, and their Holocene analogues from the Mississippi Valley.

In the general discussion on application of sequence stratigraphy and allostratigraphy after two days of full immersion, trying to avoid the conflict between words and concepts, and to consider the necessities of field geologists that deal with rock units that do not meet the strict requirements imposed by the stratigraphic guides or codes for a formal definition, some recommendations were proposed, discussed and then “voted”.

A clarification is necessary at this point: the Hedberg Conference was *not* a decision-making body, and no formal vote was cast. It was a kind of poll or straw-vote, in order to quantify the opinions expressed by the conference participants, that included as observers Dr. Jim Ogg, secretary general of the International Commission on Stratigraphy of IUGS, and the undersigned, vice-chairman of the ISSC.

The Hedberg Conference was sponsored by AAPG and even the abstract book is covered by copyright. Some keynote lectures may or may not be published together. At the time of writing this report, one month after the conference, a fortnight after the terrible September 11 that changed the world, a final, written version of the recommendations “voted” is not available yet. Anyway, they may be summarized as follows:

1. Leave sequence stratigraphy informal, and revisit the issue in - maybe - ten years from now.
2. Reconsider allostratigraphy. There is a need for defining rock units bounded by unconformities (better, by *discontinuities*) especially for continental Quaternary deposits, but also for extrusive volcanics and volcanoclastic deposits. The basic unit might be called synthem or allothem or similar, and a hierarchic approach is advisable. These units should not be restricted to the sedimentary rocks. A formal definition with definite rules is a prerequisite for a stable (versus floating or chaotic) nomenclature.
3. Avoid conflicting definitions in the International Stratigraphic Guide and in the North American Code for Stratigraphical nomenclature.

As a final comment, the Hedberg Conference succeeded to create a good, open discussion on principles and applications, with sedimentologists, micropaleontologists, basin analysts, geophysicists, geochemists, field geologists of at least three generations interacting actively. Ernest Mancini has to be gratefully acknowledged for his dynamic leadership, and Amos Salvador has to be congratulated for his patience and persistent dedication.

There were no winners and no losers in Dallas, but I got a very strong message: stratigraphy is not dead!

The lesson I learnt is that those who create the rules of stratigraphic terminology must keep some flexibility and incorporate new developments and methodologies, but should avoid to formalize interpretative definitions. Formalization ensures stability in nomenclature, which is important, but formalization of non observational entities has to be discouraged.

**INTERNATIONAL SUBCOMMISSION ON STRATIGRAPHIC
CLASSIFICATION
APPENDIX B (TO ISSC CIRCULAR NO. 100)**

WHAT IS A SEQUENCE ?

(by H. DE LA R. WINTER, Geology Department, Rand Afrikaans University,
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DEFINITION

A SEQUENCE is a unit of sustained material deposition bounded by discontinuities.

This definition has no words that can be misinterpreted, or imply limitations such as *relatively, genetically related, believed, significance, character or relation to sea level* that prevents it from being essentially a clearly scientific statement. These are debatable attributes.

As such a sequence is a stratum, the basic material unit of stratigraphy, the scientific documentation of strata. The purpose of including the word stratum, plural strata, is that the ultimate aim of stratigraphy is to measure time progression from layered rocks, and so to increase our knowledge of geohistory, leading to understanding the genesis, depositional processes and evolution of all rocks on Earth.

What is a stratum?

A stratum is a layer of rock material, solid or particulate, deposited as sediment, a volcanic product, or from an extraterrestrial source. A stratum may contain material from more than one type of source.

What makes them layered?

Interruptions in continuity make it possible to observe, record and scientifically document strata. The practical usefulness of an exercise in stratigraphy increases with the size of the area covered and the duration or time progression recorded by the deposition of strata. Various discontinuities are caused by the potential and kinetic energy released by tectonics. Hence character and sea level are inessential attributes, for example.

How do strata define time and its progression?

The Law or Principle of Superposition is a mathematical axiom defining the physical positions of undisturbed strata in time progression. Strata first deposited are older than strata subsequently deposited. Appendix B to ISSC Circular No. 99 shows the majority in the Working Group on Sequence Stratigraphy, however, believe that “the existence of diachronous unconformities precludes universal interpretation of chronostratigraphy using sequence stratigraphy.” There must be a subtle deviation from logic somewhere in their interpretation that needs to be debated *first*, because their stance contradicts a new statement of principle that **sequence stratigraphy is equal to local chronostratigraphy** and the reason why is because strata are limited by tectonics. We are not dealing with interpretations that can be falsified, but with physically documented material bodies. The cause of discontinuities in deposition, the gaps in stratigraphic representation, is tectonics. The chronostratigraphic significance of unconformity-bounded sequences [UBS] is thus explained [Refer to “Discontinuities Date Deposition” in Circular No. 98]. The new statement in bold is now the reigning valid theory. Hedberg [1978] *op. cit.* accordingly endorses that natural sequences are local and that only their time [geochronologic] equivalents can be correlated globally. The material reference to the chronostratigraphic equivalence of UBS

must be the time when there is a theoretical situation of no interruption [conformity]. Why is it necessary to actually record those positions and date them? [Also refer Appendix C to Circular 99]. Why cannot we interpolate the dates of continuous deposition from most representative stratotypes? These are important points to debate, and not only in closed working groups, but openly.

Why are there so many proposals and existing schemes for classification of discontinuous strata [UBS, allostratigraphy, synthems]? I think they all are chronostratigraphic with respect to *theoretical* material continuity, because there are likely to be more gaps than depositional time on any geologic time column [Guide, 1994, Ch. 2E]. Bear in mind that absolutely continuous sedimentation results in an absolutely uniform basin lithology, because there would be no strata to mark the difference, bar sporadic volcanic and extraterrestrial products, and no need to retain the smaller ranks of nested unconformities whose boundaries have become arbitrary towards a basin interior.

Is sequence stratigraphy a category of classification?

Natural sequences are **not** *per se* a category or class of stratigraphy! Individual strata are too small and need to be grouped or classified into units of practical size and duration. That would be the responsibility too, of ISSC, the International Subcommittee on Stratigraphic Classification.

Up to this point it is the responsibility of ICS, the International Committee on Stratigraphy of IUGS, the International Union of Geological Sciences, to accept the above before formulating their mission [See ISSC Circulars. 92 and 93]. Is it necessary to first wait for ICS agreement before carrying on? Let us rather examine the classification implications of the theory that sequence stratigraphy equals geographically limited chronostratigraphy on the basis that Hedberg's theory is valid, has not been falsified, and waits to be tested.

CLASSIFICATION

What is classification?

Hedberg [1976, p.xvii] says it is the ordering of the complexities of nature. Stratigraphers apply it to natural strata in our case. Classification is based on different attributes [Guide, 1994, 2A]. Scientific classification means that the attributes must be measured, described and then ordered.

Categories

- 1. Lithostratigraphy** for preliminary assemblage of lithologies on maps and sections.
- 2. Biostratigraphy** where available for confirmation of correlation and environment.
- 3. Chronostratigraphy** for geohistory and global *time* correlation.

There can be no doubt that only the third is essential and the most important today to include all layered rocks on Earth.

CONCLUSION

_____ This contribution is an appeal to the ICS Bureau to control the reorganisation of all Subcommissions and Working Groups, to change their programs according to Hedberg's vision of the current stratigraphic theory. Those that cannot change may have to be dissolved and others created. A proposed stepwise guide as to the procedure to manage the change has been outlined in "Discontinuities Date Deposition" in ISSC Circular 98 for consideration.

Please also make it again possible for all logical contributions to the debate on stratigraphic matters to be published. Perhaps "Episodes" is one such medium, as the voice

of ICS, but surely other journals have a democratic right to present case histories in defence of or proposed changes in stratigraphy as well. As a retired Active AAPG member of over 25 years standing with Professional Certification, I have found it most difficult to penetrate the continued blind acceptance of falsified theories by the majority of academics. Have natural scientists joined the humanities where anything goes?

TIME IS RUNNING OUT

(by H. DE LA R. WINTER, Geology Department, Rand Afrikaans University,
P.O. Box 524, Auckland Park 2006, South Africa; hdlrw@na.rau.ac.za)

INTRODUCTION

Is it a forlorn hope that the outcome of the Hedberg Research Conference will be to amend the International Stratigraphic Guide according to the prescription of Hedberg [1978], namely that **sequence stratigraphy is equal to local chronostratigraphy**?

Time is running out for introducing the radical amendments required as a consequence. Nobody wants to respond to the 1978 call of Hollis and heed the fundamental logic of the above natural law. Because of the 1999 Guide, the teaching of falsehoods in stratigraphy will continue and most journals will not accept dialogue in defence of Hedberg's revised statement of principle.

Concepts to be Discarded

1. Non-layered rock bodies have been included into the definition of stratigraphy.
2. Chronostratigraphy is wrongly said to be of global extent.
3. Chronostratigraphic unit boundaries must be physically located where deposition is continuous. Many worry about the gaps in the hierarchy. They are normal.
4. Dating rock layers to time is touted as stratigraphy rather than techniques to approach the true ages of layered rock via their relative time interval equivalents [cf. "National Geographic" Sept. 2001].
5. Contrary to the mathematical and physical principles of layered superposition, some still think that diachronous unconformities do exist.
6. To gain their objective, stratigraphers should rather reclassify chronostratigraphy, biostratigraphy and lastly by far, lithostratigraphy, in the correct order of importance. All stratigraphic units are of limited geographic extent. Lithostratigraphy hides misjudged associations and undetected fault duplications.

Currently Valid Stratigraphy

1. Stratigraphy is the scientific record of layered rocks. The purpose of the effort is to evaluate the origin and evolution these physically measured layers wherever they are encountered on Earth.
2. In a submission to ISSC Circular No. 98 with the title "*Discontinuities Date Deposition*", members can trace the contributions of three Americans, Wheeler, Sloss and Hedberg to demonstrate the equivalence of sequence stratigraphy and local chronostratigraphy that is limited by regional tectonics. Geologists from other countries have without doubt advanced in the same direction, some very significantly, possibly much more, but are not heeded. So the American dominated Working Groups have to be forced to change their favoured misconceptions, before the IUGS can accept that a new theory means that the old one is to be discarded. They have wasted critical time charging windmills! In the process, they have upset the applecart [evidence: the 1999 Guide]. The world cannot accept such leadership and is becoming increasingly restive.

3. Only time can ever be correlated globally.

The criteria recommended and referred to under point 2 need to be upheld. Those that disagree must provide valid reasons.

Why the Haste?

1. Stratigraphy, the central discipline of geology, critically controls the exploitation of the limited material resources of the world.
2. The world population explosion has passed the point where these resources can provide in the most basic needs of still growing hordes of deprived people [Cloud, Preston: "*Cosmos, Earth and Man*", Yale University Press].
3. Consequently, survival calls for extreme measures, contrary to the constitutions of the civilized world, to regain a balance. Natural balances are famine, pandemics, disasters and wars. But the terrible outburst of September 11, 2001, indicate that current normal balances are inadequate. Merciless dictators controlling and manipulating desperate masses to gain their selfish ends are blackmailing their solutions cowardly onto an unprepared world.
4. The world must apply the correct measures quickly to avoid the Armageddon. The Creator knows what they are. *Homo Sapiens* has reached the hour of critical decision making. Reading the genesis and evolution of our world accurately may help to determine what choices remain open to humankind.

**INTERNATIONAL SUBCOMMISSION ON STRATIGRAPHIC
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APPENDIX C (TO ISSC CIRCULAR NO. 100)**

CONCEPT AND DEFINITIONS IN CYCLOSTRATIGRAPHY
(SECOND REPORT OF THE CYCLOSTRATIGRAPHY WORKING GROUP)

(by FRITS HILGEN¹, WALTHER SCHWARZACHER², ANDRÉ STRASSER³,

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² School of Geography, Queen's University, Belfast, U.K.;

³ Institute of Geology, University of Fribourg, Fribourg, Switzerland)

... to correlate these with an astronomical cycle of known period, and to deduce from this correlation an estimate in years of a portion of Cretaceous time (G.K. Gilbert, 1895)

Introduction

The application of sedimentary cycles in geochronology goes back into the 19th century when Gilbert (1895) correctly linked repetitive limestone-shale alternations to the astronomical cycle of precession to determine the absolute duration of part of the Cretaceous. However, because of the often poor age control, geologists remained reluctant to link such repetitive changes to cyclic processes with identifiable time periods and often considered them to result from stochastic processes. As a consequence, the term sedimentary cycle was often defined in a purely descriptive sense to indicate "... recurrent sequences of strata each consisting of several lithologically distinctive members arranged in the same order" (Weller, 1960).

However, due to improved age control and breakthrough studies of Pleistocene glacial cyclicity in marine cores, we now can use sedimentary cycles and cyclic changes in climatic proxy records with identifiable time periods for improving the resolution and accuracy of the geological time scale and for understanding natural climate variability. The cyclic changes in the sedimentary record referred to above are related to climate variations that are ultimately controlled by variations in the shape of the Earth's orbit and the inclination of its rotational axis. They are often named Milankovitch cycles after the Serbian astronomer Milutin Milankovitch for his milestone contribution in linking orbital variation to the climatic changes of the Earth (Milankovitch, 1941).

At about the same time as the revival of Milankovitch cyclicity, the increasing concern about man-induced global warming spurred a host of detailed paleoclimatic and paleoceanographic studies of the last 10.000 to 150.000 years. These studies in particular aimed to understand natural climate variability on much shorter time scales at the extremely young end of Earth's history. For this purpose, ultra-high-resolution age models were needed and developed. The chronologies are based on annual layer counts in corals, ice cores and sediment cores from lakes and marine settings, thereby following the construction of a dendrochronology for the Holocene.

It is clear that accurate and high-resolution age models based on coherent cyclostratigraphic frameworks, and if possible integrated with biostratigraphic, magnetostratigraphic, chemostratigraphic, and tephrostratigraphic data, are an indispensable tool if we are to better understand natural climate variability and changes in sedimentary and ecological systems on different time scales. In view of the recent developments outlined above and the overwhelming evidence that cyclic variations are ubiquitously present in the geological record, time is ripe to formally define a concept of cyclostratigraphy. The aim of our Working Group, which was installed under the auspices of the International Subcommission on Stratigraphic Classification (ISSC), is to formulate such

a concept, to clarify its relationship with other schemes of stratigraphic classification, and to provide some definitions that are based on a broad consensus within our community. For this purpose, a first draft of the report was sent to all members of the ISSC as well as to a large number of specialists from various disciplines for review. Furthermore, the draft was discussed at the International Workshop “Multidisciplinary Approach to Cyclostratigraphy”, held on May 26 to 28, 2001, in Sorrento, Italy. The critical comments have been taken into account during the preparation of this revised version of the report.

Proposed concept and terminology

The term **cyclostratigraphy** was probably first publicly launched at the a meeting held in Perugia, Italy, and Digne, France (Fischer, 1988), to indicate the branch of stratigraphy that deals with sedimentary cycles and other cyclic variations in the stratigraphic record of any description but with identifiable time periods and, in particular, with their application in geochronology by improving the resolution of time-stratigraphic frameworks.

At present, the term cycle is employed in so many different ways that it has become almost meaningless. In its broadest sense, it is used to describe any regular or even irregular repetition of lithofacies in sedimentary successions, irrespective of the time involved. The members of the WG unanimously are of the opinion that **the term sedimentary cycle (as used in cyclostratigraphy) should be restricted to these repetitive changes in the stratigraphic record that have, or are inferred to have, a time significance**. Thus, individual cycles represent at least approximately equal time intervals.

The frequency stability of cyclic processes generating sedimentary cycles differs considerably. Relatively stable and therefore most useful oscillations are invariably directly connected with planetary and lunar motions. Therefore, astronomically controlled cycles are the main tool of cyclostratigraphy. They fall into different frequency bands: the calendar band with diurnal, monthly (lunar) and annual variations, the solar band with multi-annual to centennial variations, the sub-Milankovitch band with millennial variations, and the Milankovitch band with the precession, obliquity, and eccentricity orbital variations.

Some oscillations like solar activity, climatic cycles such as Dansgaard-Oeschger cycles, Heinrich events, or ENSO cycles are not yet fully explained and are less stable as far as their frequencies are concerned. Such cycles are therefore less suitable for establishing chronostratigraphic timescales, also because they can not be predicted. However, they can be of considerable use in stratigraphy. Longer-term cycles with periods of tens to hundreds of millions of years are not included here because evidence for their presence in the geological record is weak and an underlying cause has not been convincingly demonstrated.

The translation of any cyclic or near-cyclic variations of the environment into the sedimentary record involves non-linearities as well as random disturbances. It is therefore not to be expected that stratigraphic series measured by the geologist will always produce precisely predictable periods. This clearly can make the identification of astronomically controlled cycles difficult and provides one of the main challenges for the stratigrapher. The sedimentary succession may contain cycles of several orders, indicating that the system in which it formed was governed by more than one periodic process, or by a combination of periodic and aperiodic processes. In the case of Milankovitch forcing, ratios of the superimposed cycles are known and can in principle be used to extract time information irrespective of the availability of other dating tools.

In this report, it is not our intention to provide a detailed and complete overview of cyclic forcing and how this forcing is eventually recorded in the widely different depositional environments that are found on Earth. Good reviews of the different forcing mechanisms

and many examples of applying cyclostratigraphic methods are found in de Boer & Smith (1994) and House & Gale (1995). A general text is given by Schwarzacher (1993).

Methodology

The primary data are extracted from the sedimentary record in its broadest sense. This includes detailed analysis of (e.g.) lithology, facies, paleontology, mineralogy, stacking pattern of beds, geochemical proxies including stable isotopes, and/or physical properties. Very dense sampling is needed in order to obtain several data points within the smallest discernible sedimentary cycle.

Various spectral analytical methods can be employed to detect cyclicity in such records. Without time control the records can be analysed in the depth domain and the resulting frequencies of cyclic components are given in number of cycles per meter. The depth series can be transformed into a time series using widely different methods (e.g., biochronology, radioisotopic dating, magnetostratigraphic calibration, astronomical tuning) to date the records as accurately as possible and thus to obtain the necessary age calibration points. The resulting time series of the original depth record can then be analyzed by the same spectral methods. In all cases confidence levels can be added in order to indicate the significance of the cyclicities.

Links to other branches in stratigraphy

To sequence stratigraphy

The term “sedimentary cycle” as used in cyclostratigraphy differs from the terminology usually applied in sequence stratigraphy, where some authors use “cycle” to describe repetitive changes that are inferred to have time significance on at least a regional scale, but that are not necessarily periodical. Evidently, the use of the term “cycle” in sequence stratigraphy is not consistent with cycles as used in cyclostratigraphy. However, sequences that represent equal time periods such as many of the higher-order sequences according to the cycle hierarchy of Vail et al. (1991) are also “sedimentary cycles” as defined in cyclostratigraphy. On the other hand, the term “sedimentary cycle” includes many cyclic repetitions that are not sequences according to the sequence-stratigraphic concept (see definitions proposed by the ISSC Working Group on Sequence Stratigraphy).

The situation that some cyclic repetitions in sedimentary successions should be considered both as a sedimentary cycle as well as a sequence, and thus are the subject of both cyclostratigraphy as well as sequence stratigraphy, is unavoidable but not considered a problem by the members of the WG. In fact, the integration of high-resolution sequence stratigraphy and cyclostratigraphy can lead to a better understanding of the sedimentary systems and of how they react to sea-level, hydrodynamic, climatic, physical, chemical, and biological changes.

To event stratigraphy

Event stratigraphy deals with the identification and application of beds in the stratigraphic record that are caused by sudden events. Typical examples are turbidites and tempestites. As a consequence, there is no strong link between cyclostratigraphy and event stratigraphy because events are episodic rather than periodical in nature. However, individual event-stratigraphic units may occur in clusters that are related to cyclic processes.

To geochronology

The absolute age of sedimentary cycles and other cyclic variations in the Milankovitch frequency band can be determined by calibrating them to target curves, which are calculated from astronomical solutions for the Solar System. Such calibrations have been used to establish absolute time scales for the Oligocene to Recent and already underlie the standard geological time scale for the Pliocene and Pleistocene. They can be considered “anchored” since they are tied to the Recent. “Floating” astrochronologies have been established for older parts of the geological record by multiplying the number of, for example, precession-induced cycles with the expected precessional periodicity at that time. Floating time scales can be tied to biostratigraphy, chemostratigraphy, or magnetostratigraphy, which are themselves calibrated by radiometric dates.

The standard geological time scale is now based on two independent absolute dating methods. The astronomical method is used for establishing the youngest, late Neogene part of the time scale, while the radiometric method is used for the older parts. Although attempts have already been made, there is a strong need for a better intercalibration of both methods. The most recent numerical astronomical solution permits a reliable reconstruction of the orbital parameters for the last 35 million years (Laskar, 1999).

Working definitions

Cyclostratigraphy: subdiscipline of stratigraphy that deals with the identification, characterization, correlation, and interpretation of cyclic (periodic or near-periodic) variations in the stratigraphic record and, in particular, with their application in geochronology by improving the accuracy and resolution of time-stratigraphic frameworks.

Sedimentary cycle (as used in cyclostratigraphy): one succession of lithofacies that repeats itself many times in the sedimentary record and that is, or is inferred to be, causally linked to an oscillating system and, as a consequence, is (near-)periodical and has a time significance. Different cycles can be described by their period, for example as a 100-ka cycle or, if this is not precisely known, as a cycle in the order of 100 ka.

Astronomical time scale (ATS): a geological time scale with absolute ages derived from the calibration of sedimentary cycles and other cyclic variations in sedimentary successions to astronomical time series. Chron boundaries and biostratigraphic events are directly tied to such a time scale via first-order calibrations, i.e. they have been located in the same astronomically dated sections that have been used to construct the time scale. This approach is already common practice for the late Neogene part of the geological time scale.

Suggestion for a formal codification of Milankovitch cycles

At present, different codification schemes exist in the literature for sedimentary cycles and cyclic variations in oxygen-isotope records that occur in the Milankovitch frequency band of the spectrum and that have been tuned to the astronomical record. Oxygen-isotope stages have been numbered back from the Recent or have been given a numbering linked to the chron nomenclature via magnetostratigraphy. Sedimentary cycles in the Mediterranean Plio-Pleistocene have been coded after the correlative peak in precession or insolation time-series numbered back from the Recent.

However, probably the most suitable cycle for establishing a formal codification scheme for astronomically calibrated variations is the 400-ka eccentricity cycle because it is the most stable longer-term orbital cycle over prolonged intervals of time. The 400-ka cycles

can be numbered back from the Recent and subdivided into individual precession cycles. In addition the 2.3 ma eccentricity cycle might be of considerable use as well. Deeper in the geologic past, floating time scales must be tied to well-dated stratigraphic intervals. Type sections should be defined where these 400-ka and 2.3-ma cycles are particularly well developed and linked to other stratigraphical scales. Astronomically calibrated time-stratigraphic units can be incorporated in the standard geological time scale. This is particularly favorable if the standard time scale is based on these units itself.

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**INTERNATIONAL SUBCOMMISSION ON STRATIGRAPHIC
CLASSIFICATION
APPENDIX D (TO ISSC CIRCULAR NO. 100)**

FIRST CONFERENCE ON FUTURE DIRECTIONS IN STRATIGRAPHY
International Commission on Stratigraphy
Urbino, Italy
14-16 June 2002

AGENDA

Challenge from the IUGS: Global Boundary Stratotype Section and Point (GSSP) for all Phanerozoic stages in place by the year 2008.

Response from the ICS: Completion of primary mission (selection of GSSPs).
Future Direction of ICS: Geological Process Oriented Stratigraphy.

I. Response to Challenge

- A. Selection of GSSPs for all Phanerozoic stages
 - 1. Reports from each system based Subcommission to include:
 - a. Present status
 - b. Plans for completion by 2008
- B. Strategies to ensure progress within Subcommissions
 - 1. Impediments to progress (historical precedence, regional preferences, financial support, leadership, etc.)
 - 2. Methods of overcoming impediments
- C. Contributions of ICS
 - 1. Scientific results and their dissemination in papers, reports, and charts
 - 2. Development of international relationships and cooperation
 - 3. Stimulus for international conferences, symposia, field meetings
 - 4. Stratigraphic Information Services

II. Future of ICS

- A. Mission - Geological Process Oriented Stratigraphy
 - 1. New Mission: high-resolution global chronostratigraphy (developed by ICS) applied to problem of global change.
 - 2. Purpose/Future of Commission and Subcommissions
 - a. ICS - Commission or future Association
 - c. Consolidation of Subcommissions
 - b. New Subcommission on Stratigraphic Information Services
 - 3. Recruitment of young participants
 - 4. Increased scope/discipline of membership to reflect new mission
- B. Dissemination of knowledge/results/products to greater scientific community
 - 1. SIS (Stratigraphic Information Services)
 - 2. Web site
 - 3. Linkage of regional time scales to ICS standard global time scale

4. Publications/reports/charts
4. International symposia, conferences, workshops
5. KRONOS Award - International Stratigraphic Prize

III. Plans for 32nd IGC, Florence

- A. Subcommission sponsored symposia
- B. Use of global correlation to address global issues

**INTERNATIONAL SUBCOMMISSION ON STRATIGRAPHIC
CLASSIFICATION
APPENDIX E (TO ISSC CIRCULAR NO. 100)**

LITHUANIAN STRATIGRAPHIC GUIDE: NEWLY INTRODUCED TERMS

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The Lithuanian Stratigraphic Guide has been published as a pre-print in occasion with 31st International Geological Congress, Rio de Janeiro, Brazil, August 2000. The Guide concept and implementation was reported by A.Grigelis at the ISSC business meeting, on August 8, 2000, during the 31st IGC (ISSC Circular No. 98, October 27, 2000). A full complete hardbound Guide version should be published and distributed in 2001.

The Guide describes main principles of stratigraphy and contains rules of stratigraphic classification, terminology and nomenclature. The Abridged Version of the International Stratigraphic Guide will be also reproduced within the permission of the IUGS from *Episodes*, 1999, Vol. 22, No. 4, pp. 255-271. A Glossary of stratigraphic terms, wide bibliography and indexes in Lithuanian and English are given as the Supplements.

The Guide is approved by Lithuanian Commission on Stratigraphy, 16 May, 2000 and recommended for use in all geological researches.

The Guide is written in Lithuanian. A text given below contains the newly introduced terms (absent in the International Stratigraphic Guide and its Abridged version) aiming to acquaint the international community of stratigraphers.

Introduction

Each state should create national stratigraphic guides and codes to regulate rules passed for stratigraphic classification and nomenclature of rocks in a modern geological context. The present project is targeted at preparation of Lithuanian National Stratigraphic Guide by adapting principles of the International Stratigraphic Guide for the needs of Lithuania's geology. The Lithuanian Stratigraphic Guide is devoted for a wide round of geologists, which in their activities are in one or another way related to stratigraphic issues. It is especially important for unification of stratigraphic terms and regulating stratigraphic procedures at a national level. The Lithuanian Stratigraphic Guide is compiled by a Working Group of the Lithuanian Stratigraphic Commission under the guidance of ISSC member Professor Algimantas Grigelis and financially supported by the Lithuanian Geological Survey.

The present work was not thought to deal with evaluation of the stratigraphic codes and history of compilation of stratigraphic guides. The main idea was to make a basis for stability and unification of stratigraphic classification and nomenclature. The work describes fundamental general principles of stratigraphy, which are used to substantiate the modern concept of the stratigraphy. The main text is compiled on the basis of the work: Michael Murphy and Amos Salvador (*Episodes*, 1999, Vol. 22, No. 4): INTERNATIONAL STRATIGRAPHIC GUIDE. Abridged version / International Union of Geological Sciences (IUGS), International Stratigraphic Commission (IGC), and International Stratigraphic Subcommittee (ISSC). The glossary is taken from the International Stratigraphic Guide (1994) and shows wide range of stratigraphic terms in English and Lithuanian languages.

The principles used to substantiate modern theoretical stratigraphy are composed of the following standpoints. The **time dependence principle** (Stenon 1669) explains sequence in rock formation in the Earth's crust. The **homotaxis principle** (Huxley 1862) defines difference between taxonomic resemblance and synchronism which is important for geological correlation of sections. The **principle of replacement of chronological features or events** defines the essence of strata comparison for different facies, provinces and continents (Meyen 1974, 1989); it is used to substantiate correlation of local and regional stratigraphic schemes to the standard global chronostratigraphic scale. The **principle of objective reality and non-recurrence of stratigraphic units** means that the stratigraphic units reflect real geological events and their essence, they do not recur in time and space; in this sense they are unique (Stepanov, Mesezhnikov 1979). The **principle of independence of stratigraphic units** is based on the fact that deposits and rocks in Earth's crust are formed and their composition changes under greatly varying conditions according to their own typical laws.

Stratigraphic units based on lithological peculiarities are changing in time and space depending on changes in their conditions, hence, they make up a specific category of stratigraphic units - lithostratigraphic units. Therefore, even the lowest rank of stratigraphic units (local ones) is specific for the basin facies zones. Biological evolution of every group of fauna and flora proceeds on the Earth in a specific way. The biostratigraphic units - biozones - distinguished on this basis also are specific. They are not attributed to the hierarchy of chronostratigraphic units. Boundaries of organisms group biozones do not coincide mainly. The chronostratigraphic units based on correlation of coeval strata also make up an independent category of stratigraphic units. Regional stratigraphic units, e.g. regional stages, are also attributed to the latter category - they make up a specific stratigraphic scheme in a certain region or basin.

The specific (independent), often non-synchronous lithostratigraphic, biostratigraphic and chronostratigraphic units and their correlation schemes can help in properly solving local, regional and global problems of stratigraphy.

NEWLY INTRODUCED STRATIGRAPHIC UNITS

Description of stratigraphic units newly introduced by the Lithuanian Stratigraphic Guide, and some terminology and procedures are presented below.

1. General

The **categories of stratigraphic units** accepted in the Guide are as follows below. These are the formal units:

1. Lithostratigraphic units (Litostratigrafiniai padaliniai) - units based on the lithologic properties of the rock bodies.
2. Unconformity-bounded units (Sekvenciniai padaliniai) - bodies of rock bounded above and below by significant discontinuities in the stratigraphic succession.
3. Biostratigraphic units (Biostratigrafiniai padaliniai) - units based on the fossil content of the rock bodies.
4. Magnetostratigraphic polarity units (Magnetostatigrafinio poliariškumo padaliniai) - units based on changes in the orientation of the remanent magnetisation of the rock bodies.
5. Chronostratigraphic units (Chronostatigrafiniai padaliniai) - units based on the time of formation of the rock bodies.

The stratigraphic unit in Lithuanian can be also named as '**stratonas**'. Former Lithuanian and Baltic stratigraphy literature widely used the term '**horizon**' (horizontas). It

is recommended to be replaced by **'regional stage** (regioninis aukstas) or just stage (aukstas) with a corresponding geographical name: e.g. Minijos aukstas (Minija Stage), Sventosios aukstas (Sventoji Stage).

2. Editing rules and procedures (to be applied for Lithuanian terms)

i. **Capitalisation.** The first letters of all words used in the names of formal stratigraphic units are capitalised (except for the trivial names of species and subspecies rank in the names of biostratigraphic units). Informal terms are not capitalised.

ii. **Hyphenation.** Compound terms for most kinds of stratigraphic units, in which two common words are joined to give a special meaning, should not be hyphenated, e.g. 'dalinio paplitimo zona' (partial-range zone), 'kompleksinis stratotipas' (complex stratotype). Exceptions are adjectival prefixes or combining forms that are generally combined with the term-noun without a hyphen, e.g. 'biozona' (biozone).

iii. **Repetition of the Complete Name.** After the complete name of a stratigraphic unit has been referred to once in a publication, part of the name may be omitted for brevity if the meaning is clear, e.g., 'oksfordpio aukōtas' (the Oxfordian Stage) may be referred to as 'oksfordis' (the Oxfordian), or instead of 'silūro sistema, periodas' (the Silurian System, Period) may be written 'silūras' (the Silurian). Such abbreviations are not used for the Quaternary units.

3. Unconformity-bounded units

Unconformity-bounded units (Sekvenciniai padaliniai) are objective stratigraphic units determined and recognised without genetic and causal interpretation of the unconformity limiting them. In English they are named as unconformity-bounded units ('padaliniai apriboti nedarnomis'), however, the stratigraphy branch dealing with them is sequence stratigraphy ('sekvencinē stratigrafija'). Therefore this Lithuanian term is proposed. Sequential stratigraphy method in Lithuania just started to be introduced. It may be especially useful in oil geology, geodynamics analysis and palaeogeography, where up to now the large systems are described by chrono- or lithostratigraphic terms. Basic type of sequential unit is **Synthem (sintema)**.

4. Biostratigraphic units

Two formal unit types have been described in the category of biostratigraphic units.

4.1. Ecozone (Ekozona)

a. **Definition.** It is the ecostratigraphic unit distinguished according to fossils found in it and peculiarities of sedimentation environment.

According to its definition the ecozone contains features both of biostratigraphic and lithostratigraphic units. Therefore their ascription to the category of biostratigraphic units is rather conditional.

b. **Boundaries.** The boundaries of the ecozone are defined by changes in ecological and ecology of the geological section, and related biological alteration of a taxon.

c. **Name.** Ecozone is named after the taxon or taxa reflecting certain ecological conditions.

4.2. Interzone (Interzona)

a. **Definition.** Strata without zonal taxon or fossils occurring between zones or fossils; intermediate zone (tarpinė zona).

Geological section not always contains continuous sequence of zones, especially those having no phylogenetic links. Therefore a break in the biozone sequence can be taken as an interzone.

b. **Boundaries.** The lower boundary of the interzone is defined by the upper boundary of an underlying zone, whereas the upper boundary coincides with the lower boundary of the overlying zone.

c. **Name.** The name of the Interzone is double - it consists of the names of underlying and overlying zones, e.g. 'Monograptus balticus-Monograptus formosus interzona'.

4.3. Comments

It should be noted that besides biostratigraphic zones (biozones) the biohorizons ('biohorizontai') could be distinguished. These are very thin beds or relatively isochronous surfaces in the palaeontologically based strata base or top. The interval between two well-defined biohorizons can make up an interval zone.

If, on the basis of several archistratigraphic fossil groups, biozones of different type are distinguished in the same geological section, the zone boundaries can coincide or do not coincide; the latter case is more often, since acceleration of biological evolution of each group of the organic world differed and life of taxa was different.

Each biozone with zonal taxon or taxa contains also zonal complex (association of fauna or flora) of several taxa, that should be mentioned in the description. If no zonal taxon is found (especially in well sections, where palaeontological finds are rare), the zone can be singled out by its zonal complex as well.

Biozones, distinguished according to any plant or animal group, make up zonal stratigraphic scale. If isolation of such biozones is based on phylogenetic evolution of a group, such a scale, theoretically, should not contain zone-free section intervals, i.e. interzones. If biozones are distinguished without taking into account phylogenetic principle and the section contains interzones, such biozones will make up the zonal stratigraphic scheme of that group.

5. Chronostratigraphic units

Lithuanian Stratigraphic Guide recommends both formal and regional chronostratigraphic units and its geochronological equivalents.

5.1. Regional formal stratigraphic units

a. **Definition.** Regional stratigraphic unit comprises rocks formed in a depositional basin or palaeogeographical province (region) in a certain stage of geological evolution (time interval); it reflects their sedimentation peculiarities, sequence of fauna and flora complexes, and structural-tectonic changes. Regional stratigraphic unit is attributed to the chronostratigraphic category.

Regional stratigraphic units are independent; they make up regional stratigraphic scheme and global (standard) stratigraphic scale (Table 1).

Table 1

| | | |
|---|--|---|
| Chrostratigrafiniai terminai Chronostratigraphic terms | Geochronologiniai terminai Geochronological terms | Litostratigrafinio padalinio atitikmenys Equivalents of lithostratigraphic units |
| Regioninis aukstas Regional Stage | Ampius Age | Kelios svitos, svita arba jos dalis Several formations, formation or its part |
| Regioninis poaukstis Regional Substage | Poampis Subage | Svita arba jos dalis Several formations, formation or its part |
| Regioninis sluoksnis Regional Bed | Laikas Time | Svita, sluoksniai, pluostas Formation, beds, member |

Boundaries of regional stratigraphic units are determined by changes in sedimentation regime and stratigraphic breaks, basic changes of fauna and flora, climate and structural scheme. Boundaries of these stratigraphic units at the unit base and top are determined by synchronous coeval horizons, whereas lateral boundaries are defined by those of a palaeobasin and/or palaeogeographical province - these boundaries changed in a complicated way in time under the influence of Earth's crust movements and eustatic World Ocean level fluctuations.

b. **Taxonomic Units.** Taxonomic units of regional stratigraphic units are represented by regional stage, regional substage and regional bed.

c. **Regional Stage (regioninis aukstas).** Regional Stage is traditional chronostratigraphic unit, according to a rank it makes a part of Stage, in terms of global standard scale. The Regional Stage is basic unit of regional stratigraphy. This is the "horizon" used in earlier works, but the term of horizon in this Guide gets another more accurate meaning.

Regional Stage possesses exceptional lithological, palaeontological and other features and performs the most important correlation function in the area of its geographic distribution. The Regional Stage correlates with coeval units: formation (svita), formations

(svitos), groups (serijos) or their parts, and other lithostratigraphic and biostratigraphic units. Name of the regional stage can be the same as that of typical, well-explored, and coeval formation (svita) or to be independently attributed.

Phanerozoic regional stages and their correlation is mainly based on palaeontological and (if available) radiological data, i.e. as for other chronostratigraphic units. They reflect regional development as well as that of palaeobasin, palaeogeographical province fauna and flora and peculiarities of their changes.

In Precambrian or “fossil-less” Phanerozoic strata regional stages can be distinguished on the ground of lithological, facies and petrographic features of rocks, by providing isotope-geochronological data. Quaternary regional stages usually are based on climatostratigraphic data.

The Regional Stage should have a stratotype or areal stratotype.

d. **Regional Substage (regioninis poaukstis).** Regional Stage can be divided into substages (poaukstis), or in rare cases - into superstages (antaukstis) (distinguishing is not recommended). In a geological section the regional substage makes a lithologically and palaeontologically defined part of regional stage recognized in full area of its distribution. Regional substages must occupy all sequence of the regional stage and be named as: lower (apatinis), upper (virsutinis) or lower (apatinis), middle (vidurinis), and upper (virsutinis) together with the name of the regional stage. If regional stage is divided into 4 substages, each of them should have a separate geographic name. From geochronological point of view the regional stage corresponds to the age (amzius), and the regional substage to the subage (poamzis), e.g. Minija age in the Silurian.

e. **Regional Bed (regioninis sluoksnis).** This is the smallest chronostratigraphic unit inside the regional stage or regional substage; it is important for facies correlation in a palaeobasin. The Regional Bed is distinguished on the ground of lithological, palaeontological and other features; in the geological sections it is recognized as a chrono-marker, but it is not necessary that it filled all stratigraphic space of the regional stage or regional substage. It can be based by formations (svita), beds (sluoksniai) or member (pluostas), if they can be widely traced in a basin and have relatively coeval (isochronous) boundaries. Stratotype of the regional bed can be distinguished in a stratotype of regional stage or indicated in the stratotypes of lithostratigraphic units basing them. It is named after a geographic name of a stratotype or a locality where its features are most distinct, e.g. Ancia Regional Bed in the Silurian. The regional bed corresponds to the time (laikas), e.g. Sakyna time in the Ordovician.

f. **Description and Naming Rules.** Description of a new regional stratigraphic unit requires the following data given: (1) name, after the rules of the Lithuanian Stratigraphic Guide, (2) geographic distribution and composition, (3) main correlation features, substantiation of boundaries, (4) stratotype site, its description or reference to a source of description, (5) position in the regional stratigraphic scheme, (6) stratigraphic division of the unit, (7) relation to earlier distinguished coeval regional units, (8) relation to regional stratigraphic units of the neighboring regions, and (9) geological age (relation to the units of the global stratigraphic scale).

5.2. Subdivision of the Precambrian

In order to make the Lithuanian Precambrian stratigraphy classification and terms uniform, the following recommendations are proposed.

Boundaries of Precambrian geochronometric units are defined by million years (Ma, Ga), without references to real rock bodies. These boundaries comprise and single out the most important cycles of sedimentation, orogenesis and magmatism. Hence, the Precambrian is divided into two eons: Archean and Proterozoic. The Archean is divided into free units, but they are not instituted by authorized international organizations. The Proterozoic is divided into 3 eras and 10 periods. Division of the Proterozoic prepared by Precambrian Stratigraphic Subcommittee (SPS) of the International Stratigraphic Commission (ICS) is ratified by International Union of Geological Sciences (IUGS) in 1990 (Plumb, 1992), but the discussions about it continue.

Basic methods applied for division of the Precambrian into chronostratigraphic units are lithostratigraphic ones and radiological dating. Application of lithostratigraphic classification - i.e. distinguishing of rock beds and grouping them into stratigraphic units on the base of their lithology and petrography and stratigraphic links - depends on degree and type of rock metamorphism and deformation. In the cases of low metamorphisation and small deformations, principles of sequence stratigraphy can be applied. In the cases of high metamorphisation and large deformations, the biggest official lithostratigraphic units - group (serija) and formation (svita) - are recommended to be distinguished at least. If only bedded fragments (supracrustal formations) mixed with rocks of other genetical types (magmatic, metasomatic) are found to have been survived, big unofficial units - complex (kompleksas), strata (storymè) - should be distinguished.

In the later cases distinguishing of lithostratigraphic units and their correlation can be based on tectonostratigraphic principles by defining stratigraphic units to be distinguished by their formation's tectonic environment (tectonic facies, tectofacies) determined by petrological-geochemical methods. Relative stratigraphic sequence of such units is determined by regularities in tectonic position (tectofacies) defined in the global tectonic of lithosphere plates (Wilson cycle and other).

Absolute age of the Precambrian lithostratigraphic units distinguished and their regional and global correlation can be based only on radiological (isotope) dating data. Each lithostratigraphic unit distinguished in such a way must have typical locality that should contain a sufficient set of rocks unified into that unit and it should be defined by a set of methods sufficient for determination of tectonic facies of the unit.

5.3. Quaternary stratigraphic units

The recommendations set up to make Lithuanian Quaternary stratigraphy classification uniform.

A. Criteria for stratigraphic subdivision. Quaternary stratigraphic subdivision is made by applying climatostratigraphic criterion. Application of this criterion depends on a type of deposits and geographical position of the area. To determine the rank of the unit, two basic features (criteria) are used: (1) amplitude of climate fluctuations, and (2) time duration. The boundary between the stratigraphic units is drawn by applying climatostratigraphic criterion.

B. Key investigation methods. To determine climate type and duration of a change, the following research methods can be applied: palaeontological, bioindicational, lithological, isotopic, geochemical, physical, etc.

C. Stratigraphic units. The hierarchy of Quaternary units comprises two-type units: climatostratigraphic and lithostratigraphic (Table 2). Lithostratigraphic units are distinguished only in the cases when application of climatostratigraphic criterion is impossible.

C.1. Climatostratigraphic units

Climatostratigraphic units are as follows: series (skyrius), division (skaidma), subdivision (skirsnis), step/climatolith (pakopa, klimatolitas), stadial (stadialas), phasial (fazialas), and oscillation (osciliacija).

i. Series (skyrius). According to the International Stratigraphic Chart (2000) Pleistocene and Holocene deposits are attributed to it.

ii. Division (skaidma). Division is the largest climatostratigraphic unit. Pleistocene deposits formed during a long complicated period of climatic changes are attributed to it. It can comprise several large climatic rhythms. These deposits are notable for certain non-repeated successions of fauna and flora and specific climate history. Series [division] has no stratotype; its stratigraphic size is defined by stratotypes of lower ranked unit's as subdivision, and/or step.

Table 2

| Klimatostratigrafiniai padaliniai (ir ju geocronologiniai ekvivalentai) Climatostratigraphic units (and its geochronological equivalents) | Litostratigrafiniai padaliniai Lithostratigraphic units |
|--|--|
| Sistema (periodas) System (Period) | |
| Skyrius (epocha) Series (Epoch) | |
| Skaidma (laikas) Division (Time) | |
| Skirsnis (laikas) Subdivision (Time) | Serija Group |
| Pakopa (klimatolitas) (ledynmetis arba tarpledynmetis) Step (Climatolith) (Glacial or Interglacial) | Svita Formation |

| | |
|---|-------------------------|
| Stadialas (stadija) (kriostadialas arba termostadialas) Stadial (Stadium) (Cryostadial or Thermostadial) | Posvitė Subformation |
| Fazialas (fazė) (kriofazialas arba termofazialas) Phasial (Phase) (Cryophasial or Thermophasial) | Pluostas Member |
| Osciliacija arba chronozona (laikas) Oscillation or Chronozone (Time) | Sluoksnis Bed |

Boundaries of the stratigraphic unit are assumed to coincide with those of lower-rank units within the series: lower one goes as the lower boundary of the oldest unit, and the upper one goes as the upper boundary of the youngest unit. A geochronological equivalent of series is epoch, and of division is time.

iii. Subdivision (skirsnis). Subdivision is a climatostratigraphic unit lower in rank than series [division], but higher than the step/climatolith. Deposits of several rhythms (glacial plus interglacial) with typical biostratigraphy and climatostratigraphy are attributed to it. They can be without a stratotype. Stratigraphic size of the subdivision are defined by stratotypes of lower-rank units present within it. The boundaries of subdivision are assumed to coincide with those of smaller units: the lower one goes at the lower boundary of the oldest unit, whereas the upper one coincides with the upper boundary of the youngest unit. A geochronological equivalent of the subdivision is time.

iv. Step/Climatolith (pakopa/klimatolitas). Step/Climatolith is the basic climatostratigraphic correlation unit, lower in its rank than subdivision, but higher than stadial. Deposits formed during global cold (ice age) or warm (interglacial) periods are attributed to the step. Step can have its own name, a stratotype and boundary stratotype. Its name should be related to geographic or historical name of the stratotype locality; the best case would be the relation with stratotype's name. Stratotype can be related to an area: for the ice age - the deposit sections in that area, where there are data for determining stratigraphic position of the step deposits; for the interglacial - sections of one palaeobasin. Boundaries between the stratigraphic units are drawn after the climatostratigraphic principle. To draw a boundary lithology of deposits, alteration of phyto- or zoo-associations (climate indicators) and other climate fluctuation features can be used. A geochronological equivalent is the name of the step plus a word 'glacial', or the name of the step plus the word 'interglacial'.

Note: Ice Age is a period of cold climate, when Lithuania or its part were under the continental ice cover. Interglacial is a warm climate interval between two ice ages. During a period of optimal climate, broad-leaved forests or mixture of broad-leaved and coniferous stands are formed, the climate was warmer than that in present-time Lithuania, or the same as now.

v. Stadial (stadialas). Stadial is a climatostratigraphic unit lower in its rank than step but higher than phasial. Deposits formed during cold or warm climate periods, when

smaller climatic fluctuations took place and caused changes in landscape, vegetation and glaciers (advance or retreat) are attributed to the stadial. Taking into account the type of climatic the taxonomic unit can be supplemented with a prefix 'cryo-' for colder period and 'thermo-' for warmer one. Hence, cryostadial was notable for subarctic or arctic climate. In the thermostadial, there was warmer climate that caused re-emigration of mesothermal plants. The stadial must have its stratotype. The stratotype can be related to an area. Its geochronological equivalent is stadium.

vi. Phasial (fazialas). Phasial is a climatostratigraphic unit lower in rank than stadial but higher than oscillation. Deposits formed during a glacial, when climatic changes caused local changes in landscape and ice cover dynamics (advance) are attributed to the phasial. It must have its stratotype. A geochronological equivalent of the phasial is phase.

vii. Oscillation (osciliacija). Oscillation is a climatostratigraphic unit lower in rank than phasial. Deposits formed during ice age at very small climatic fluctuations which caused small shifts in ice cover boundaries in a limited area are attributed to the oscillation. Its geochronological equivalent is oscillation time.

viii. Cryomer (kriomeras). Cryomer is a climatostratigraphic unit lower in rank than the step. Deposits formed during a colder period of glacial. The term is to be used in the cases, when palaeogeographic conditions of their formation are unclear.

ix. Thermomer (termomeras). Thermomer is a climatostratigraphic unit lower in rank than a step. Deposits formed under warmer period of glacial are attributed to the thermomer. The term is recommended to be used in the cases, when palaeogeographic conditions of their formation are unclear.

C.2. Lithostratigraphic units

Lithostratigraphic units are as follows: group (serija), formation (svita), subformation (posvitė), member (pluostas), and bed (sluoksniš).

i. Group (serija). Group is the largest lithostratigraphic unit higher in rank than formation. This taxonomic unit is applied for the deposits of two or more adjacent formations notable for the same diagnostic lithological characteristics. The term is to be used in the case when conditions of deposit formation are not clear enough.

ii. Formation (svita). Formation is a key lithostratigraphic unit comprising lithologically related deposits. From geochronological point of view one formation can be an equivalent of a step or to make a part of the latter. Formation determines sedimentation processes of a definite geological period in a definite area. It should possess rather obvious lithological-facial or palaeontological features in this area. Size of a formation is assessed after the deposits formed during the full time interval defined. Deposits occurring in the area defined, although some details in diagnostic features may differ from a stratotype, are attributed to the formation. The formations has its stratotype. It can be of areal type.

iii. Subformation (posvitė). Subformation is a lithostratigraphic unit smaller than formation. The subformation comprises lithologically related deposits; it makes a part of a formation. The term is to be used in the case when palaeogeographic conditions of deposit formation are not clear enough.

iv. Member (pluostas). Member is a lithostratigraphic unit comprising lithologically similar deposits formed under slightly changed palaeogeographic conditions. The member makes a part of a subformation.

v. Bed (Sluoksniš). Bed is a lithostratigraphic unit smaller than a member and comprising short-term sedimentation deposits of the same lithology, structure and other features.

D. Rules for distinguishing and description of a unit

Describing a new stratigraphic unit, except for oscillation (osciliacija) the following data are to be given: (1) unit name according to the rules indicated in the Lithuanian Stratigraphic Guide, (2) geographical distribution of deposits, (3) general facial and lithological characteristics of the deposits, (4) deposit thickness (it can be average) and its range, (5) link with the over- and underlying deposits, (6) palaeontological characterization, (7) type of climate conditions and its development trends, (8) geological age, (9) detailed description of a stratotype and its detailed address, (10) substantiated correlation of the stratotype with typical sections of adjacent areas, and (11) substantiated correlation of the unit with the stratigraphic units of the adjacent areas.

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