

**Phanerozoic environmental changes in the Caucasus and adjacent areas:
stratigraphy, fossil diversity, mass extinctions,
sea-level fluctuations, and tectonics**

by
Dmitry Aleksandrovitch Ruban

Submitted in partial fulfillment of the requirements
for the degree

DOCTOR OF PHILOSOPHY

in the
Faculty of Natural and Agricultural Sciences
University of Pretoria

Pretoria
December 2008

Phanerozoic environmental changes in the Caucasus and adjacent areas: stratigraphy, fossil diversity, mass extinctions, sea-level fluctuations, and tectonics

Dmitry A. Ruban

Sworn statement before a commissioner of oaths

Herewith, I state that none of the 21 papers included in the present thesis was submitted by me elsewhere for a PhD or any other degree. For 7 co-authored papers, a clarification of the relative contribution of each author is stated below.

Ruban, D.A. & Tyszka, J. 2005. Diversity dynamics and mass extinctions of the Early-Middle Jurassic foraminifers: A record from the Northwestern Caucasus. Palaeogeography, Palaeoclimatology, Palaeoecology. 222: 329-343.*

* corresponding author

Ruban: recalculation and interpretation of data on the Northwestern Caucasus, regional versus global comparisons, development of the general concept of the paper and writing its major parts

Tyszka (Institute of Geological Sciences, Cracow Research Center, Polish Academy of Sciences, Poland): data and interpretations on the Polish regions taken for a comparison, general editing of the paper and writing some of its parts (including those concerning the Polish regions and preparation of figures)

Ruban, D.A. & Yoshioka, S. 2005. Late Paleozoic - Early Mesozoic Tectonic Activity within the Donbass (Russian Platform). Trabajos de Geología. 25: 101-104.*

*corresponding author

Ruban: writing of the whole manuscript, including development of the main tectonic concept

Yoshioka (Kyushu University, Japan): general editing of the paper

Tawadros, E., Ruban, D. & Efendiyeva, M. 2006. Evolution of NE Africa and the Greater Caucasus: Common Patterns and Petroleum Potential. The Canadian Society of Petroleum Geologists, the Canadian Society of Exploration Geophysicists, the Canadian Well Logging Society Joint Convention. May 15-18, 2006. Calgary. P. 531-538. [extended abstract]*

*presenting author

Tawadros (petroleum consultant, Canada): characteristics of the Phanerozoic evolution of the Northeastern African basins; discussion of the comparison between NE Africa and the Greater Caucasus and their hydrocarbon potential; general editing of the paper (including figures)

Ruban: characteristics of the Phanerozoic evolution of the Greater Caucasus; discussion of the comparison between NE Africa and the Greater Caucasus and their hydrocarbon potential; preparation of the key illustrations

Efendiyeva (Geological Institute, National Academy of Science, Azerbaijan): data on the Eastern Caucasus; data on the petroleum reserves of the Azerbaijan Hydrocarbon Province

Ruban, D.A., Al-Husseini, M.I. & Iwasaki, Y., 2007. Review of Middle East Paleozoic Plate Tectonics. GeoArabia. 12: 35-56.

no corresponding author is indicated; all authors contributed equally

Ruban: interpretations of data on the Caucasus and some other regions of the Middle East, comparison of available tectonic reconstructions, preparation of the initial draft of the manuscript, general editing of the paper

Al-Husseini (Gulf PetroLink, Bahrain): writing the chapters on some regions, preparation of the final draft of the manuscript, general editing of the paper, drawing the figures (with support of Gulf PetroLink technical staff)

Iwasaki (American Museum of Natural History, USA): interpretation of the Devonian paleogeography on the basis of trilobite analysis, general editing of the paper

Ruban, D.A. & van Loon, A.J. 2008. Possible pitfalls in the procedure for paleobiodiversity-dynamics analysis. Geologos. 14: 37-50.*

* corresponding author

Ruban: writing the whole manuscript and development of the main concepts

van Loon (Adam Mickiewicz University, Poland; Netherlands): addition of some general considerations on paleodiversity analysis, editing of the paper (with a preparation of the final draft) and drawing the final versions of its figures

Gutak, Ja.M., Tolokonnikova, Z.A. & Ruban, D.A. 2008. Bryozoan diversity in Southern Siberia at the Devonian-Carboniferous transition: new data confirm a resistivity to two mass extinctions. Palaeogeography, Palaeoclimatology, Palaeoecology. 264: 93-99.*

*corresponding author

Gutak (Kuzbass State Pedagogical Academy, Russia): providing the data for geological context of the paper (stratigraphy, paleoenvironmental interpretations)

Tolokonnikova (Kuzbass State Pedagogical Academy, Russia): providing the initial data on bryozoan stratigraphic ranges and taxonomy, preliminary drawing of some figures (except those demonstrating the main results)

Ruban: data recalculation and interpretation, regional versus global comparisons, discussion of data in paleoenvironmental context, writing the whole manuscript and drawing of figures

Zorina, S.O., Dzyuba, O.S., Shurygin, B.N. & Ruban, D.A. 2008. How global are the Jurassic-Cretaceous unconformities? Terra Nova. 20: 341-346.*

*corresponding author

Zorina (Central Research Institute of Geology of Industrial Minerals, Russia): data on the eastern part of the Russian Platform, discussion of the paper's general concept

Dzyuba (Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of Russian Academy of Sciences, Russia): data on West and East Siberia, discussion of the paper's general concept

Shurygin (Trofimuk Institute of Petroleum Geology and Geophysics, Siberian Branch of Russian Academy of Sciences, Russia): data on East and West Siberia, discussion of the paper's general concept

Ruban: development of the general concept of the paper, compilation and interpretation of data from many regions across the globe (including incorporation of data given by 3 other co-authors), discussion of eustatic curves, examination of possible causes of eustatic drops, writing the whole manuscript and drawing of all figures

/D.A. RUBAN/

Phanerozoic environmental changes in the Caucasus and adjacent areas: stratigraphy, fossil diversity, mass extinctions, sea-level fluctuations, and tectonics

Dmitry A. Ruban

SUMMARY

Table of contents

1. *Introduction and main objectives*
 - 1.1. *Geological setting of the studied regions*
 - 1.2. *General purpose of this study*
 - 1.3. *Main objectives*
 2. *Materials and methodological framework*
 - 2.1. *Materials*
 - 2.2. *Methods*
 3. *Stratigraphy*
 - 3.1. *Lithostratigraphy*
 - 3.2. *Biostratigraphy*
 - 3.3. *Chronostratigraphy*
 4. *Fossil diversity*
 - 4.1. *Specific methods*
 - 4.2. *Triassic biota*
 - 4.3. *Jurassic biota*
 - 4.4. *Phanerozoic evolution of brachiopods*
 - 4.5. *Interregional comparisons of diversity trends*
 5. *Mass extinctions*
 - 5.1. *Frasnian/Famennian mass extinction*
 - 5.2. *Permian/Triassic mass extinction*
 - 5.3. *Triassic/Jurassic mass extinction*
 - 5.4. *Pliensbachian/Toarcian mass extinction*
 - 5.5. *Jurassic/Cretaceous mass extinction*
 - 5.6. *Aalenian event*
 - 5.7. *Geohistorical study of Mesozoic mass extinctions*
 6. *Sea-level fluctuations*
 - 6.1. *Facies analysis*
 - 6.2. *Paleozoic sea level*
 - 6.3. *Triassic sea level*
 - 6.4. *Jurassic sea level*
 - 6.5. *General conclusions*
 7. *Tectonics*
 - 7.1. *Paleozoic-Triassic terrane model*
 - 7.2. *Jurassic geodynamic reconstructions*
 - 7.3. *Phanerozoic phases of the tectonic evolution of the Greater Caucasus*
 8. *Concluding remarks*
- Acknowledgements*
- Publications included in the present thesis*
- Suggestion of order in which papers should be read*
- References*
- Subject index*

1. Introduction and main objectives

1.1. Geological setting of the studied regions

The Caucasus is a large region, which occupies the territory of southwestern Russia, and all of Georgia, Armenia, and Azerbaijan. It is dominated by two subparallel mountain chains, namely the Greater Caucasus (which includes the Main Caucasian Range with the highest European peak - Mt. Elbrus) and the Lesser Caucasus, which both stretch between the Black Sea and the Caspian Sea. The geological structure of the Caucasus is complicated (Fig. 1). It includes two main domains, also referred to as the Greater Caucasus and the Lesser Caucasus, which are divided by two Transcaucasian depressions, i.e., the Rioni Depression and the Kura Depression (Fig. 2). A large area, which lies to the north of the Caucasus, is the so-called Ciscaucasus, which is a young stable platform developed over Paleozoic structures. A famous Late Paleozoic coal-bearing basin, named the Donbass, forms something of a branch or offshoot, derived from the Ciscaucasus. This basin cuts off the Russian Platform, whose southern block is the so-called Ukrainian Massif with its eastern edge being known as the Rostov Dome (Fig. 3). The geological evolution of the Ciscaucasus, the Donbass basin, and the Rostov Dome was linked closely to that of the Caucasus.

1.2. General purpose of this study

The Caucasus is often regarded as a typical Alpine region, because the present-day Caucasian geological architecture is dominated by structures developed during the Alpine phases, i.e., during the Cenozoic (Ershov et al., 2003; Tawadros et al., 2006). Undoubtedly, the Caucasus is an important section in the Alpine active belt, which stretches from the Atlantic Ocean to Southeast Asia, but the evolution of the Caucasus and the Alps might have been connected even more strongly, especially in the Late Paleozoic-Early Mesozoic. The geology of the Caucasus provides a rich source of information on the Phanerozoic paleoenvironmental changes, which should not only be discussed in a regional framework, but also in the global context. The key position of the Caucasus, between the Alps and Carpathians in the west, the Iranian and Central Asian domains in the east, the Precambrian Russian Platform (craton) in the north, and the Turkish domains in the south, makes the Caucasus a very important region to discuss the changes in the regional paleoenvironments. These changes can help to enhance our understanding of the evolution of the whole Tethyan sector. Unfortunately, the data from the Caucasus are only rarely used in determining these large-scale geological constraints, and the Caucasian region appears to be largely ignored (with very few exceptions) in international geology. My study is aimed at providing some essential knowledge on the Phanerozoic record of the Caucasus and adjacent areas (the Donbass and the Rostov Dome).

The conclusions from the attempted studies were published in international journals. Twenty one articles are included in this thesis, and a number of other papers are in press, accepted or submitted.

1.3. Main objectives

- A compilation of litho-, bio-, and chronostratigraphic information in order to constrain the modern stratigraphic framework and to recognize spatial changes in the sedimentary architecture in the Caucasus and the Rostov Dome.
- A careful compilation of a vast amount of already published paleontological data on various fossil groups from the Paleozoic-Mesozoic of the Caucasus, including

brachiopods, bivalves, ammonoids, and foraminifers. These data are essential for further constraints of diversity dynamics.

- An examination of general trends in the Paleozoic-Mesozoic fossil diversity in the Caucasus with a special attention to brachiopods as the most diverse and the best studied group.
- A recognition of the regional signatures of the Frasnian/Famennian, Permian/Triassic, Triassic/Jurassic, Pliensbachian/Toarcian, and Jurassic/Cretaceous mass extinctions in the Caucasus.
- An evaluation of Paleozoic and Triassic-Jurassic transgressions, regressions, and changes in basin depth in the Caucasus on the basis of facies analysis and with the use of the constrained stratigraphic frameworks. Regional sea-level changes are to be brought in correspondence with the global eustatic curves. It is always important to evaluate possible relationships between fossil diversity and sea level changes.
- A development of new models of the Phanerozoic tectonic evolution of the Greater Caucasus and the Late Paleozoic-Triassic evolution of the Donbass. These regional models are made with respect to global plate tectonics, accounting for terrane displacements, activity of planetary shear zones, and continental breakups.
- New paleotectonic constraints help in the interpretation of the regionally-documented paleoenvironmental changes. On the other hand, the stratigraphical and paleontological conclusions make possible important improvements in the regional paleotectonic constraints.
- Interregional comparisons of the geological events are essential to discuss similarities and dissimilarities of the geological evolutionary processes and to establish geological analogues of the Caucasus and adjacent areas.

Although the entire Phanerozoic record of the Caucasus and adjacent areas is examined, I emphasize the Devonian-Jurassic time interval, whose stratigraphical, paleontological, and tectonic record is the richest, the most diverse, and, therefore, the most intriguing. The unusual Neogene record of the Rostov Dome is examined in detail (Ruban, 2005a).

2. Materials and methodological framework

2.1. Materials

All stratigraphical data used to perform my studies were collected during field studies in the Western and Central Caucasus (1996-2008), in the Donbass Basin (1996-2006), and in the Rostov Dome area (1996-2002). Field excursions in Azerbaijan (2007) and the Swiss Alps (2008) under the guidance of the local specialists also helped to strengthen an understanding of some geodynamic interpretations.

In the Caucasus, a number of sections and outcrops were investigated (Fig. 4). Among them are the Lipovyj section of the Early Toarcian deposits (probably accumulated on a rocky shore) (Fig. 5), the Bezymjannaja section of the transitional Aalenian-Bajocian crinoid limestones (limestones of this age were first found by the author in the Western Laba-Malka Area), the Khadzhokh-2 section of the condensed Callovian siliciclastics with an exceptionally abundant fossil assemblage, and many others (Fig. 6). Composite sections are delineated in order to summarize stratigraphic data from particular sets of sections and outcrops (e.g., Fig. 7). It is necessary to emphasize that an analysis of composite sections is crucial because of two reasons. Firstly, very few outcrops extend significantly over continuous sections in the Caucasus. Secondly, the very large size of the Caucasus area requires summarizing of the data. For example, Jurassic composite sections are constructed (Ruban, 2007a) for each particular area distinguished within the Caucasus, by lithologic peculiarities by Rostovtsev et al. (1992) Twelve suitable (i.e. good outcrops) sections of the

Upper Miocene deposits were investigated in the Rostov Dome area (Figs. 8, 9). The information deduced from these sections is presented and interpreted in papers included into this thesis (see list below).

Paleontological sampling was oriented mainly for stratigraphic purposes. Some representative samples are stored in my private collection (Appendix 1). An examination of stratigraphic ranges of some common invertebrate species permitted a re-evaluation of the age of the strata. For example, a comparison of the brachiopod assemblage from the crinoid limestones of the Dzhangurskaja Formation with the characteristic assemblages of Western Europe (Cariou & Hantzpergue, 1997) permitted me to confirm an Aalenian age of these beds, which had been questioned in earlier literature (Rostovtsev et al., 1992).

A careful compilation of already published paleontological data on various fossil groups (e.g., see appendices 5, 6) was supported by a critical examination of the hundreds of published sources on regional geology and paleontology to minimize uncertainties, misinterpretations (especially stratigraphic), and problems with taxa synonymy. All earlier-published data on fossils were enhanced where possible, some with the assistance of European and American specialists, who corrected taxonomic lists and justified the suprageneric taxonomy for some fossil groups (e.g., Y. Almeras, M. Bécaud, - Jurassic brachiopods; A.J. Boucot - suprageneric taxonomy of Permian-Jurassic brachiopods; M. Bécaud - Early Jurassic ammonites; N.M.M. Janssen, W. Riegraf - belemnites; A.A. Kasumzadeh, W. Schätz - Triassic bivalves). General regional paleontological overviews were considered together with publications based on case studies in order to avoid sampling errors. All datasets are aimed to be representative. Field and literature data are always incorporated as accurately as possible to reach their best confidence levels. For example, discovery of Middle Jurassic crinoid limestones in the Western Laba-Malka area and a discussion of their age permitted the re-positioning of some facies distributed widely within the Greater Caucasus at the regional stratigraphic scale (Ruban, 2007a). This enabled the timing of the local sea-level fall to be estimated.

2.2. *Methods*

The methodological framework of this study is multidisciplinary, and it comprises several steps of studies. Firstly, the regional (litho-, bio-, chrono-) stratigraphic frameworks are improved, particularly to bring these in line with the present chronostratigraphical developments of the International Commission on Stratigraphy (ICS) of the International Union of Geological Sciences. For example, a position of the base-Aalenian boundary was justified according to the GSSP (Global Stratotype Section and Point) in Fuentelsalz with data on ammonoids and foraminifers. The regional Upper Miocene stages of the Eastern Paratethys were replaced with the global stages approved by the ICS on the basis of correlation of absolute stage boundaries (Ruban, 2005a). The next step was the compilation of all available paleontological data. For this purpose, stratigraphic ranges of particular taxa were summarized in a series of datasheets (appendices 2, 3; see also Ruban, 2004, 2006a,b,d, 2007c, 2008; Ruban & Tyszka, 2005). This allows the establishment of a number of trends in the fossil diversity changes, and the documentation of mass extinctions (and also to hypothesize a new mass extinction, in the Aalenian). It is necessary to note, that theoretical background of fossil data in preparation for further quantitative analysis was considered (Ruban & van Loon, 2008). To address possible problems with sampling errors and taxa interpretations, the author visited collections of Triassic bivalves stored at the Geological Institute of the Azerbaijan National Academy of Sciences (Baku), where they are curated by A.A. Kasumzadeh. To reveal sea-level changes, datasets of composite lithologic sections are used (e.g., Ruban, 2007a). Facies analysis (see 6.1) was applied in order to interpret these data. Special attention was also paid to the paleotectonic reconstructions. Those already

existing are mostly based on the outdated geosyncline paradigm and the so-called formation analysis (e.g., Laz'ko, 1975). In contrast, I attempt to apply modern concepts of plate tectonics and terrane analysis. Interregional comparisons of lithologic and paleontologic data (Ruban, 2007b,d) as well as tracing of the major unconformities (Ruban, 2007b) permitted me to recognize the key large-scale tectonic events, well-known and well-interpreted in the regions of Europe and Middle East, and, thus, to reach conclusions about their nature within the study areas for this thesis. For example, the mid-Permian unconformity is well traced in the Variscan structures of Europe, where it is known as a Saalian unconformity (in some localities, as a series of unconformities). Thus, a Saalian phase of tectonic activity can be hypothesized in the Greater Caucasus (Ruban, 2007b).

Some very specific methods used for the purposes of the present study are discussed in the relevant chapters below.

3. Stratigraphy

Regional litho-, bio-, and chronostratigraphy of the Caucasus and adjacent areas is improved in order to obtain a much improved stratigraphic framework and to permit precise interregional correlations.

3.1. Lithostratigraphy

Hundreds of formations are established in the Phanerozoic succession of the Caucasus and adjacent areas, but an especially complicated situation occurs with the Jurassic strata of the Caucasus and the Upper Miocene strata of the Rostov Dome. In the first case, formations were established originally in 36 particular areas for the Hettangian-Bathonian interval and in 26 areas for the Callovian-Tithonian interval. The author's re-examination of available data as well as his own field studies permitted some measure of updating of the knowledge of these lithological packages (Ruban, 2007a). In particular, an investigation of outcrops in the basin of the River Belaja led to the recognition of the so-called Bizhgon Member (Rostovtsev et al., 1992), composed of crinoid detrital pink-colored limestones, which was not established in the Western Laba-Malka area by previous studies. Investigation of faunal assemblages permitted me to date this member and to change its position in the regional lithostratigraphic scheme, which is important for further paleogeographical constraints. I also re-examined and documented in detail the stratotype section of the Kamennomostskaja Formation (Ruban, 2007b), i.e., the Khadzhokh-2 Section (Figs. 4, 6). This sheds a new light on a very uncertain description of this important section, which is one of a very few exposed Callovian sections in the Caucasus. Although this formation was established earlier, its re-examination confirms a striking lithological distinction from the under- and overlying sedimentary complexes to fulfill the ICS requirements (an angular unconformity at the base of this formation is traced to separate it from the Triassic flysch deposits; although lithologically heterogeneous, this formation is characterized by a dominance of clastics in contrast to the overlying carbonates). The Upper Miocene strata represented by skeletal limestones cover the Rostov Dome entirely. However, no formations were defined there until now, except for the Janovskaja Formation. I established a set of new formations and suggested their precise correlation (Ruban, 2005a). All reference and other key Upper Miocene sections of the Rostov Dome were investigated (Figs. 8, 9), and as a result the Taganrogskaja, Rostovskaja, Donskaja, Merzhanovskaja and Aleksandrovskaja Formations were first recognized, and their logs were documented (Ruban, 2005a). Facies-based logs are yet to be published, although facies interpretations for each section were carried out. Establishing their spatial relationships provides a necessary clue to reveal the dynamics of past shorelines of the Paratethys Sea.

Three additional tasks related to lithostratigraphy were also resolved. First, a composite Paleozoic lithological section of the northern part of the Greater Caucasus was constructed,

with an indication of the main sedimentary packages (Ruban, 2006a, 2007b). Secondly, the Triassic lithostratigraphy of the Western Caucasus was revised, taking into account previous constraints, new suggestions, and the field observations (Ruban, 2006b, 2008) (Fig. 7). Thirdly, four major unconformities are recognized in the Paleozoic-Mesozoic succession of the Greater Caucasus - in the Ordovician, mid-Permian, Triassic/Jurassic, and mid-Jurassic. These are described, correlated, and explained (Ruban, 2007b). The first three of them have clear analogs in adjacent regions of Europe and the Middle East. The Jurassic unconformities known from the Greater Caucasus are discussed in a very broad global context in order to trace the planetary-scale sedimentation breaks (Zorina et al., 2008). It thus seems that the Triassic/Jurassic unconformity is of global extent.

3.2. Biostratigraphy

The previous biostratigraphic subdivision of the Jurassic of the Caucasus based on ammonites was quite detailed, but required updating because of numerous corrections to the Jurassic time scale during the two past decades. In order to resolve this important task, I re-examine biostratigraphic data and provide an improved version of the inferred biozonation (Ruban, 2006c, 2007a). New data permit new determinations of the positions of the Aalenian/Bathonian and Tithonian/Berriasian boundaries in the regional record. The validity of ammonite zones is confirmed, but they are also compared with the data on other fossil groups like brachiopods and foraminifera. Ammonite- and foraminifera-based biostratigraphic units are correlated and also justified according to a regional lithostratigraphic subdivisional scheme (Ruban & Tyszka, 2005). A totally new biostratigraphic scheme is developed for the Upper Miocene deposits of the Rostov Dome (Ruban, 2005a). An abundance of bivalve remains permits identification of the principal bioevents (first and last occurrences) and enabled me to outline the *Tapes vitalianus* Interval Zone, the *Cerastoderma fittoni*-*C. subfittoni* Total Ranges Zone, the *Congerina panticapaea* Interval Zone, the *Congerina amygdaloides navicula* Total Range Zone, and the *Monodacna pseudocattilus*-*Prosodacna schirvanica* Interval Zone. These new units are brought into correspondence with the new formations noted above in section 3.1. The biostratigraphic units established in the Upper Miocene of the Rostov Dome are local, although they can serve as startpoints for a further definition of bivalve-based biozones of the entire Eastern Paratethys. In all cases, mentioned above, potential effects of fossil re-sedimentation and reworking (in terms of the present taphonomic concepts) were accounted for as accurately as possible.

3.3. Chronostratigraphy

The chronostratigraphic subdivisions used for the Caucasus and the Rostov Dome are updated according to the newest developments and recommendations of the International Commission on Stratigraphy. A three-fold subdivision of the Permian is traced in the Western Caucasus (Ruban, 2007b). A clear distinction of the Norian and the Rhaetian stages in the regional record is confirmed (Ruban, 2008). The justified Jurassic chronostratigraphic framework is extended to the entire Caucasus (Ruban, 2006c, 2007a). Additionally, globally-recognized stages are traced within the Upper Miocene strata of the Rostov Dome (2005a). A correlation of local biozones to such global stages as the Serravallian, the Tortonian, and the Messinian is based on the available absolute ages of their boundaries (for global stages, very precise dates provided at the Global Stratotype Sections and Points (GSSP's) are considered).

The improvement in the regional stratigraphic framework detailed above provides a comprehensive basis for further discussion of data and results of their interpretations, in the global context.

4. Fossil diversity

4.1. *Specific methods*

Taxonomic diversity is analyzed for the entire marine fauna of the Caucasus and its counterparts, and specifically for the particular fossil groups, including brachiopods, bivalves, ammonites, belemnites, and foraminifers. The data used to measure the changes in the fossil diversity of the Caucasus are compiled from numerous available sources. After a compilation, they have been examined critically and improved according to the current taxonomy. A total of about 1000 valid species are considered. Special attention is paid to the Triassic and Jurassic periods, which were characterized by the most marked richness of the local faunas, although the Paleozoic record is not omitted. For the purposes of this study, a number of standard and new methods are used. The general principles of paleobiodiversity studies are outlined by Ruban & van Loon (2008), who give the main techniques and possible solutions to the common problems. The standard methods include quantitative analyses of total diversity dynamics, and changes in the number of originated/appeared and extinct/disappeared taxa. To make a clear distinction between originations-extinctions and appearances-disappearances, it is crucial to take into account the probable influences of interruptions in taxa stratigraphic ranges. These temporal gaps are brought into correspondence with the so-called Lazarus-effect. I propose a way, if not to minimize it, to at least account for it as accurately as possible (Ruban & Tyszka, 2005; Ruban & van Loon, 2008). The initial calculation of the total diversity or number of appearances and disappearances is followed by the same calculation, but with data hypothesizing the probable presence of a taxon at a time of its registered gap in the regional record. Thus, the highest probable value (HPV) of diversity indices is evaluated. A measurement of the HPV for the diversity of the Early-Middle Jurassic foraminifers of the Northwestern Caucasus indicates its large dimensions. At the same time, this does not affect significantly the data interpretation nor trends in diversity measured without accounting for the Lazarus-effect.

Two special indices are proposed to investigate the evolutionary rates of fossil groups (Ruban & Tyszka, 2005; Ruban, 2006d, 2007c, 2008; Gutak et al., 2008). The first R-method is a simple calculation of the Jaccard's similarity for successive faunistic assemblages, where the number of common taxa in two comparable intervals is related to their whole diversity. The result shows a rapidity of changes in the assemblage composition through the geological time interval. The Rst-method is based on a calculation of the so-called pair-correlation between successive or non-successive assemblages. For each of the latter, the presence of higher-ranked taxa is indicated by the number of lower-ranked taxa, by which the former are represented in a given assemblage. This permits an evaluation of the rate of transformation of the taxonomic diversity structure. It shows the changes in the controls of lower-ranked taxa (e.g., species) by those that are higher-ranked (e.g., genera). This new method seems to be a powerful tool to document the fundamental changes, re-organizations, and turnovers in faunistic evolution. Moreover, its application to non-successive assemblages (e.g., a comparison of the Cambrian and the Jurassic assemblages) may provide some important clues to the understanding of the overall fossil evolution. To test the new Rst-method with data from any region outside the Caucasus is crucial to weigh up its efficacy and probable limits. For this purpose, I chose the Devonian bryozoans of Southern Siberia (it might have been connected with the Greater Caucasus by the chain of Kazakh terranes). Similarly informative conclusions are made (Gutak et al., 2008). Moreover, a triplicated calculation of the Rst indices (for species-genera, genera-family, and species-family taxonomic levels) reveals transformations in both generic and familial controls of the whole diversity for the studied group.

4.2. *Triassic biota*

The Triassic fossil record is best preserved in the Western Caucasus (Appendix 2). The total marine biodiversity was quite low in the Early Triassic as a consequence of the Permian/Triassic mass extinction. However, a strong radiation, which can be judged as a regional "diversity explosion" occurred in the Anisian, when the number of species trebled (Ruban, 2006b). This was followed by a new drop in species numbers in the Ladinian. Then, a stepwise growth in the marine biodiversity set in, and reached a peak in the Late Triassic with its rich reefal assemblages. It is interesting to document a difference in the dynamics of particular fossil groups. Whereas the Anisian was a favorable time for the entire marine fauna, brachiopods and ammonoids declined sharply in the Ladinian, whereas the species diversity of bivalves and foraminifers decreased only a little. Ammonoid assemblages were very poor in the Carnian, when a strong repopulation of brachiopods, bivalves, and foraminifers began. Foraminifers declined somewhat in the Norian, which is characterized by the very high diversity of other groups, and also by an appearance of algae, corals, and sponges, not known from the older intervals. In contrast, no bivalves are found in the Rhaetian strata despite a high diversity of other marine organisms. This suggests an absence of any simple relationships between the diversity dynamics of the overall marine population and that of the particular groups of fossils. The R- and Rst-methods are used to reveal the evolutionary rates of the Triassic macrofauna (Ruban, 2008). Until the middle of the Late Triassic, they remained very high. Each younger assemblage differed from its predecessor fundamentally with a complete turnover in taxonomic composition. However, the Norian and the Rhaetian assemblages were much more similar. An analysis of non-successive assemblages leads to another intriguing observation. The Early Triassic marine macrofauna differed from that of the Anisian more strongly than from the younger Ladinian-Carnian. However, the Norian-Rhaetian assemblages were renewed significantly.

4.3. *Jurassic biota*

During the Jurassic, the number of bivalve, brachiopod, belemnite, ammonite, and foraminiferal species changed in a distinct way (Ruban & Tyszka, 2005; Ruban, 2006d, 2007a). The number of bivalve species remained low throughout the Early Jurassic. Then, it rose stepwise with a strong peak in the Callovian-Oxfordian. However, a rapid decline occurred in the Kimmeridgian-Tithonian (Ruban, 2006d, 2007a). The brachiopod diversity fluctuated strongly (Ruban, 2006a, 2007a). The peaks were reached in the Pliensbachian, the Bajocian, and the Oxfordian, whereas diversity minimums are registered in the Early Toarcian, the Early Aalenian, the Bathonian, and the Kimmeridgian. The number of ammonite species was the highest in the Late Toarcian, the Bajocian, and the Early Callovian (Ruban, 2007a). Belemnite assemblages remained highly diverse during the Pliensbachian-Bathonian, whereas they were limited before and after this time interval (Ruban, 2007a). Finally, radiations of foraminifers in the Pliensbachian, the Late Toarcian-Early Aalenian, and the Late Bajocian are registered (Ruban & Tyszka, 2005). The only fossil groups which demonstrated clear trends in total diversity changes throughout the Jurassic, were bivalves (a trend towards a diversification) and ammonites (a trend towards a decline).

4.4. *Phanerozoic diversity of brachiopods*

The especially detailed studies are addressed to brachiopods (Ruban, 2004, 2006a, 2007c), bivalves (Ruban, 2006d), and foraminifers (Ruban & Tyszka, 2005). Brachiopods are known from the entire Cambrian-Cretaceous interval of the northern part of the Greater Caucasus (Appendix 3). Their first radiation occurred in the mid-Cambrian (Ruban, 2006a). Then, they diversified in the Late Silurian (Ludlow-Přidoli)-Early Devonian. A somewhat stronger radiation took place throughout the Frasnian-Famennian. But the highest diversity of the Paleozoic brachiopods is recorded in the Late Permian (Lopingian), when dozens of taxa

appeared. A new radiation occurred during the Triassic with the highest diversity observed at the Late Triassic-Early Jurassic interval (Ruban, 2006a). This trend was interrupted by the Ladinian event, when brachiopods disappeared from the regional record totally. Since the Middle Jurassic, the number of brachiopod taxa decreased, although this trend was interrupted by a few short-term peaks (Bajocian, Tithonian). During the Early Cretaceous, the Caucasian brachiopod assemblages remained impoverished. A detailed investigation of the Early-Middle Jurassic diversity dynamics of brachiopods permits me to conclude that fluctuations in their total diversity were induced by various combinations of origination and extinction rates (Ruban, 2004). In particular, the rise in species number during the Late Sinemurian-Early Pliensbachian occurred together with an acceleration of both origination and extinction rates, whereas a collapse of the origination rate seems to be no less responsible for the Late Pliensbachian-Early Toarcian crisis than strengthening in the extinction number. Some very intriguing results are brought by the application of the Rst-method (Ruban, 2007c). A strong turnover in the structure of assemblages occurred during the Early Triassic-Anisian. However, it was much lower during the Late Triassic and in the Early-Middle Jurassic. An analysis of non-successive assemblages indicated a stability of the Late Triassic structure of taxonomic diversity. But it also shows clearly a significant similarity of the Pliensbachian, Toarcian, and Aalenian assemblages to those of the Early Triassic. Thus, the superfamilies, which dominated the species diversity in the Early Triassic, re-established their control since the Jurassic. This provides support to hypothesize a partial re-setting of the brachiopod evolution, which can be linked to the influence of mass extinctions (see below). Such a totally new conclusion is of great importance, because it gives a new view of the fossil resistance to environmental stress. An analysis of diversity dynamics of the Jurassic bivalves also suggests a complicated interaction of the origination and extinction rates (Ruban, 2006d). In particular, it appears that the strong Callovian diversification occurred thanks to an acceleration in the origination rate, whereas the extinction rate slowed somewhat in the Bathonian. The Rst-method indicates an intensification of turnovers in bivalve assemblages in the Early Jurassic, at the Bathonian-Callovian and Kimmeridgian-Tithonian transitions. An examination of the Early-Middle Jurassic foraminiferal assemblages indicates somewhat less intense fluctuations at the species and, especially, at the generic levels (Ruban & Tyszka, 2005). An interaction between origination and extinction rates can be viewed, for example, at the Late Toarcian-Early Aalenian diversity peak. A very low number of extinctions before the Late Toarcian coupled with a prominent acceleration of the origination rate during this interval led to a remarkable growth of the total diversity. Then, the extinction rate strengthened, but it was still recompensated by the number of originations. Thus, no changes in the total diversity occurred in the Early Aalenian. But both an increase in extinctions and a drop in originations led to the succeeding decline of foraminifers. This study also implies that different diversity dynamics between species and genera is possible for the same fossil group and the same time interval. The R- and Rst-methods suggest a low degree of transformation in the composition of assemblages. Even those relatively strong turnovers that occurred at the Pliensbachian-Toarcian and the Aalenian-Bajocian transitions were not so intense. Again, a difference between species and generic levels is observed.

4.5. Interregional comparisons of diversity trends

Quantitative evaluations of the fossil diversity in the Caucasus are compared with data from the other regions (the Swiss Alps, the Bakony Mountains, the Pieniny Klippen Belt) and considered against global constraints. Despite regional peculiarities in faunal evolution, general trends and events are recognized in the Caucasus (Ruban, 2004, 2006a,b,d, 2007c; Ruban & Tyszka, 2005), which suggests its exceptional importance for global biodiversity studies. Various factors were responsible for the regional diversity dynamics. These may be a

growth of reefal communities in the Late Devonian, the Late Permian, the Late Triassic, and the Late Jurassic (Ruban, 2006a), abrupt basin deepening in the Ladinian (Ruban, 2006a), marine anoxia during the Early-Middle Jurassic (Ruban, 2004; Ruban & Tyszka, 2005), an onset of a major carbonate platform in the Callovian (Ruban, 2006d), a regional salinity crisis in the Kimmeridgian-Tithonian (Ruban, 2006a,d), changes in the paleotemperatures throughout the Jurassic (Ruban, 2006b), and some others. However, special attention is paid to the role of sea-level changes, which is discussed below. It is found that different fossil groups were not similar in their susceptibility and resistance to the influences of the above-mentioned factors. Foraminifers (Ruban & Tyszka, 2005) and bivalves (Ruban, 2006d) were more tolerant of oxygen depletion than brachiopods (Ruban, 2004). However, the latter were less affected by the regional salinity crisis than bivalves (Ruban, 2006d).

5. Mass extinctions

A number of mass extinctions are established in the Caucasus and studied in detail (Ruban, 2004, 2006a, 2007c, 2008; Ruban & Tyszka, 2005). Some other catastrophes (known elsewhere) are not documented, but their traces and possible consequences for the biotic evolution are discussed. The studied crises include those of the Frasnian/Famennian, Permian/Triassic, Triassic/Jurassic, Early Jurassic (Pliensbachian/Toarcian), and Jurassic/Cretaceous. The most detailed record is available to explore the Early Jurassic mass extinction, which seems to have been not less devastating than the representatives of the famous "Big Five" (Ruban & Tyszka, 2005). A potentially new mass extinction is also registered in the Aalenian.

5.1. Frasnian/Famennian mass extinction

The Frasnian/Famennian mass extinction appears to be the only event, which appeared globally, but did not stress the regional faunal evolution in the Caucasus. A radiation of brachiopods throughout the entire Late Devonian took place, although a turnover at the Frasnian/Famennian boundary is established (Ruban, 2006a). It is important to note, that the Famennian assemblage was dominated by cyrtospiriferids, which also diversified in some other regions during this age. The study of bryozoans from Southern Siberia, a region probably connected with the Greater Caucasus by a chain of the Kazakh terranes, demonstrates that this group was always a successful survivor from the Frasnian/Famennian catastrophe (Gutak et al., 2008).

5.2. Permian/Triassic mass extinction

The Permian/Triassic mass extinction led to an overall collapse of the regional faunas. The marine diversity remained diminished during the Early Triassic, and its full recovery was not completed even by the end of the Triassic (Ruban, 2006a, b). However, it is very important to note that this recovery started very early after the extinction peak. The presence of a characteristic brachiopod taxon, which indicates the base of the Triassic, is outlined as evidence for this (Ruban, 2006a). Moreover, the first bivalve assemblages were dominated by the well-known recovery taxa of *Claraia* (Ruban, 2006b). It appears that an acceleration of the evolutionary rates of the Triassic marine macrofauna of the Western Caucasus was another recovery pattern (Ruban, 2008).

5.3. Triassic/Jurassic mass extinction

The Triassic/Jurassic transition is interrupted by a hiatus in the Caucasus, and, thus, the relevant crisis cannot be documented directly (Ruban, 2007b). However, Ruban (2007c) suggests that the Rst-method applied for non-successive Triassic-Jurassic brachiopod assemblages permits one to investigate the possible influences of this mass extinction on the

regional evolution of this fossil group. A comparison of the taxonomic diversity structure of the Rhaetian, Sinemurian, and Pliensbachian assemblages indicates their continued similarity. Such superfamilies as Spiriferinoidea and Zeillerioidea played an important role in both the Late Triassic and Early Jurassic assemblages and, thus, were not wiped out by the mass extinction. This conclusion contrasts with results from the same data, re-calculated from the Swiss Alps, where a significant turnover is registered at the Triassic-Jurassic transition (Ruban, 2007c). It is, however, interesting that the taxonomic diversity structure of the Caucasian brachiopods in the Early Jurassic resembled that in the Early Triassic. This permits me to hypothesize a partial resetting of the regional evolution of this group as a consequence of the Triassic/Jurassic event. These results underline, in general, that the new Rst-method can be a powerful means to explore the traces of catastrophes, even those misplaced from the regional record.

5.4. Pliensbachian/Toarcian mass extinction

The Early Jurassic (Pliensbachian/Toarcian) mass extinction is documented in the Caucasus with precision. It affected brachiopods (Ruban, 2004, 2006a, 2007c) and to a lesser extent, foraminifers (Ruban & Tyszka, 2005). The diversity analysis of bivalves, ammonites, and belemnites (Ruban, 2006d, 2007a) does not indicate any catastrophic patterns in the Early Jurassic. Brachiopods declined strongly already in the Late Pliensbachian (Ruban, 2004). This was preceded by their abnormal radiation. In the Early Toarcian, brachiopods disappeared entirely and no taxa are known from the relevant deposits. A repopulation began in the Middle Toarcian, but even the Late Toarcian diversification did not recompensate for the diversity loss at the Pliensbachian/Toarcian boundary. The results from the Rst-method suggest an intense turnover at this boundary (Ruban, 2007c). Moreover, this mass extinction led to a complete renovation of the taxonomic diversity structure. If the Pliensbachian assemblage is quite similar to that of the Rhaetian, a striking difference between the Toarcian and the Rhaetian assemblages is established. Surprisingly, a similarity of the Toarcian taxonomic diversity structure to that of the Early Triassic was noted, which suggests that the superfamilies which were important for species diversity after the Permian/Triassic catastrophe also found the post-Early Jurassic mass extinction conditions favorable. The total foraminiferal diversity decreased in the Early Toarcian by 1.8 times at the species level, but only by 1.2 times at the generic level (Ruban & Tyszka, 2005). The R-method indicates a strong turnover among species directly at the Pliensbachian/Toarcian boundary, whereas the same turnover among genera was somewhat delayed, occurring in the Middle Toarcian. The Rst-method permits me to document a very prominent turnover at the time of the mass extinction. The value of the Rst index is lowest in the Jurassic. Thus, my studies imply an evident occurrence of the Early Jurassic mass extinction in the Caucasus. The regional record provides evidence that oxygen depletion (related to the oceanic anoxia) was one of the probable explanations of this catastrophic event. A difference in the regional sea-level changes from those documented globally does not permit one to consider them as a possible trigger of the mass extinction, at least in the Caucasus (Ruban, 2004; Ruban & Tyszka, 2005).

5.5. Jurassic/Cretaceous mass extinction

The Jurassic/Cretaceous mass extinction stressed brachiopod assemblages strongly. Their total diversity decreased by about 10 times (Ruban, 2006a) with just a few species known from the Berriasian. Despite their recovery during the Valanginian-Hauterivian time interval, the pre-extinction diversity was never reached again. Thus, one may hypothesize that the Jurassic/Cretaceous mass extinction was a prelude to the final brachiopod collapse in the Northern Caucasus.

5.6. Aalenian event

In addition to these regional signatures of the well-known mass extinctions, it appears that the regional data provide evidence for a new mass extinction, which occurred in the Aalenian. Brachiopods almost disappeared in the Early Aalenian, but recovered rapidly in the Late Aalenian (Ruban, 2004). The total species diversity of foraminifera declined by 1.7 times in the Late Aalenian, whereas the total generic diversity decreased throughout the entire Aalenian (Ruban & Tyszka, 2005). The assemblage turnover was as large as that at the Pliensbachian/Toarcian boundary. The gradual recovery embraced the Early Bajocian, and it did not recompensate for the diversity loss. Evidently, data from only one region is not enough to speculate about new mass extinctions. However, brachiopods collapsed during the Aalenian in the Bakony Mountains of Hungary and in the Swiss Alps, whereas foraminiferal assemblages were stressed in the Pieniny Klippen Belt of the Carpathians and probably in Spain. The likely cause of this event was also an oxygen depletion.

5.7. Geohistorical study of Mesozoic mass extinctions

Besides an analysis of regional data, I attempt a geohistorical investigation of the data published in the middle of the XIX century by A. d'Orbigny (Ruban, 2005b). Their quantitative assessment permitted me to conclude that almost all Mesozoic mass extinctions (Triassic/Jurassic, Jurassic/Cretaceous, Aptian, Cenomanian/Turonian, and Cretaceous/Paleogene) might have been documented already 150 years ago. Thus, despite a remarkable growth in the available paleontological information and the description of thousands of new species, the quality of the fossil record necessary to identify mass extinctions did not change significantly. This conclusion is very significant for our understanding of the completeness of the fossil record and its further changes.

6. Sea-level fluctuations

An investigation of sea-level changes is an important clue to the understanding of the regional Phanerozoic environmental changes and biotic evolution. The data available from the Caucasus reveal the regional transgressions, regressions, and basin deepening/shallowing events for the Cambrian-Jurassic time interval.

6.1. Facies analysis

All constraints are based on a careful facies analysis. Recognition of the general facies types is suitable for the attempted studies, and each facies is interpreted within a set of diverse geological information, which included lithology, sedimentary structures and textures, fossil assemblages, relationship with contemporary facies in adjacent areas, and relationship of facies in a stratigraphic succession etc. (Ruban, 2007a). Mixing or misinterpretation of facies due to similar lithological peculiarities is avoided. For example, a clear distinction between the Norian shelfal siliciclastics and the underlying Ladinian-Carnian flysch deposits is made despite their general similarity. Another example comes from the Early Jurassic, where marine and non-marine strata both containing abundant plant remains were distinguished. Geospatial analysis of facies, used to reveal the basin dynamics, takes into account possible deviations of trends observed in log or on a regional scale from some stereotypic assumptions. A very typical example is a deposition of evaporites in the Late Jurassic. Although evaporite sedimentation is often linked to sea-level lowstands, this was associated with a highstand (that occurred just after a transgression maximum) in the Caucasus. Moreover, evaporitic sedimentation did not prevent the growth of coral reefs (a comparable situation is also known from the Miocene of the Mediterranean), and, thus, a carbonate platform became something like a substrate for the development of an evaporitic basin. Moreover, a consideration and a

semi-quantitative or quantitative analysis of facies is done en-masse, which a priori diminishes the likelihood of interpretation errors.

The sets of interpreted and compiled facies data (e.g., Ruban, 2007a) can be seen to be important. They may serve for further quantitative interpretations, which would permit to delineate particular surfaces (maximum flooding surfaces or sequence boundaries) or to discuss the sedimentary input and its influences on the basin dynamics. A global tracing of hiatuses (Zorina et al., 2008) suggests the importance of such studies for an evaluation of global eustatic changes and planetary-scale sedimentary evolution.

6.2. Paleozoic sea level

An analysis of distribution and a facies interpretation of the Paleozoic deposits in the Greater Caucasus permits the construction of paleogeographic frameworks for 9 time slices, and enables documentation of the principal changes of the shoreline (Ruban, 2007d). The Greater Caucasus was embraced by the sea in the Cambrian, which was followed by an Ordovician regression. A new transgression occurred in the Early Silurian and the shoreline along the northern border of the Greater Caucasus remained stable until the Late Devonian, whereas an opening of a new Paleotethys Ocean occurred in the south. A strong Famennian transgression led to the drowning of the entire region. The sea regressed in the Mississippian and occupied a restricted area until the Late Permian, when a new transgression took place. This general picture is detailed by the study of three principal Late Paleozoic transgressive episodes, which took place in the Lochkovian, the Frasnian-Famennian, and the Changhsingian (Ruban, 2007e). The second of them was the largest. All these episodes occurred at times of global sea-level rise, which implies their eustatic origin. Although regional tectonics did not affect them greatly, local tectonic activity may explain why evidence for the other global sea-level rises do not appear in the Greater Caucasus. An interesting observation is that these three transgressions coincided with important episodes of carbonate deposition.

6.3. Triassic sea level

The Triassic sea-level changes are reconstructed with precision (Ruban, 2008). A rapid transgression took place already in the Early Induan and the position of the shoreline remained stable until the Anisian, when its stepwise basinward shift took place. The next transgression, although smaller in its extent, began in the Ladinian, whereas a regressive episode is known from the mid-Carnian. A very strong transgression took place in the Early Norian with a peak in the middle of this stage, and a regressive episode embraced the Middle-Late Rhaetian. During the entire Triassic, the basin was, however, of a shallow-water character, with a unique exception. The Ladinian transgression coincided with a prominent deepening pulse. Both global eustasy and regional tectonic activity controlled these basin dynamics, and some major global sea-level changes are depicted in the regional record.

6.4. Jurassic sea level

The dynamics of the Caucasian basins in the Jurassic are reconstructed semi-quantitatively on the basis of a careful facies analysis in all particular areas of the region (Ruban, 2006d, 2007a). Some special attention is also paid to the Laba-Malka area (Ruban, 2004; Ruban & Tyszka, 2005). A stepwise transgression took place throughout the entire Late Sinemurian-Toarcian interval with a peak at the Toarcian-Aalenian transition. It was followed by a shorter regression in the Aalenian. Then, a rapid transgression occurred in the Early-Middle Bajocian to be followed by a longer regressive episode in the Late Bajocian-Bathonian. A major landward shoreline shift was realized during the Callovian-Oxfordian, and the Kimmeridgian was generally a time of maximum extent of marine environments,

although interrupted by a short-term regressive episode. A profound regression occurred in the Tithonian. The changes in the average basin depth differed significantly. Three deepening pulses occurred in the Pliensbachian, the Late Aalenian, and the Late Bathonian. Despite a large transgression in the Late Jurassic, the Caucasian basins did not become deeper. These conclusions are confirmed by the specific study of the Greater Caucasus Basin (Ruban, 2007a). It is found that both eustasy and regional tectonic activity controlled the reported transgressions, regressions, and changes in the basin depth. The most interesting example of a dissimilarity of global and regional records comes from the Toarcian, where a significant delay of a transgression in comparison to the global and other regional records is documented.

6.5. General conclusions

The attempted studies of the sea-level changes and a comparison of their results with the global constraints permit some very important conclusions. First, it becomes evident that transgressions-regressions differed from the changes in the basin depth. This observation is of great methodological importance, because it makes urgent a constraint of two individual curves for every particular region. Secondly, both eustasy and tectonics are important factors for the dynamics of the basin shoreline and depth. It is interesting, that although the Greater Caucasus and also the entire Caucasus remained active regions throughout the analyzed Cambrian-Jurassic interval, the signatures of many globally-recognized eustatic events are clear from the studied territory. To discuss the importance of sedimentary input requires some further modelling. However, it appears that sedimentary input played a lesser role in its influence on transgressions/regressions (except in the case of deltaic systems) than on deepening/shallowing episodes. Finally, the role of sea-level changes in the fossil diversity dynamics is discussed (Ruban, 2004, 2006a, 2006d, 2007a, 2008; Ruban & Tyszka, 2005). Some positive relationships are found. All Paleozoic transgressions coincided with biotic radiations. The episodes of reefal growth in the Late Devonian, the Late Permian, the Late Triassic, and the Late Jurassic all corresponded to transgressions. An abrupt deepening of the basin in the Ladinian stressed the marine fauna and led to a total disappearance of brachiopods. However, the only fossil group, whose diversity changes were well connected to the interaction of transgressions and regressions was the ammonites. Responses of bivalve, brachiopod, belemnite, and foraminifer diversity were more complicated and did not demonstrate simple relationships with basin dynamics. The most surprising is the fact, that links between fossil diversity dynamics and eustatic changes are more evident on a global scale than on a regional level (Ruban, 2007a).

7. Tectonics

7.1. Paleozoic-Triassic terrane model

A critical revision of the available lithological, paleontological, and other kinds of geological data from the Caucasus and adjacent areas with regard to the modern plate tectonic reconstructions for the Paleozoic and Mesozoic allows one to reconsider the tectonic evolution of the study territory and to propose a totally new model. The latter is discussed by Ruban (2006c, 2007b,d,f) and Ruban et al. (2007). This model is based on two major observations, namely (1) a similarity of the Late Paleozoic sedimentary and fossil records of the Greater Caucasus and some Hunic terranes, including the Carnic Alps and the Bohemian Massif, and (2) evidence for an arc-arc collision in the Caucasus during the Middle Jurassic. The similarity of the geological histories of the Greater Caucasus, the Carnic Alps, and the Bohemian Massif suggests their mutual proximity in the Late Paleozoic. If this was so, the Greater Caucasus Terrane was a part in the chain of the Hunic terranes derived from the Gondwanan margin in the middle of the Silurian due to the opening of the Paleotethys Ocean.

In the Late Devonian, these terranes became anchored at the Laurussian margin in the Proto-Alpine area. This interpretation raises the question as to how the Greater Caucasus could have reached its present position far to the east. An appropriate explanation is given by a consideration of the major shear zone along the northern margin of the Paleotethys. Dextral displacements along this zone during the Late Paleozoic-Middle Triassic led to terrane stacking in the Proto-Alpine area. However, the direction of displacements along this zone changed radically from dextral to sinistral in the Middle-Late Triassic. This provided a mechanism to displace the Greater Caucasus Terrane to the east, where it collided with the Russian Platform. Such a scenario explains also a major unconformity documented at the Triassic-Jurassic transition (Ruban, 2006b). This shear zone was a part in the net of Intrapangaean shear zones, which stretches across Western Europe, eastern North America, South America, South Africa, and Australia. The situation at the northern Paleotethyan margin in the Late Paleozoic-Early Mesozoic was a bit similar to that at the western margin of North America in the Mesozoic-Cenozoic (Ruban, 2007f). Not only the Caucasus, but all of the southern periphery of the Russian Platform was influenced by the activity along the shear zone. Right-lateral displacements led to the derivation of the Ukrainian Block from the Russian Platform and opening of a rapidly-subsiding coal-bearing basin (Donbass) in between (Ruban & Yoshioka, 2005). A change to left-lateral displacements in the Middle Triassic resulted in the closure of this basin and a local deformation phase, which created the Donbass fold belt. This model is well supported by the most recent dating of the tectonic activity in the Donbass. Moreover, the Paleozoic geodynamics of the Greater Caucasus Terrane, which was a part of the Hunic Superterrane, and of the Lesser Caucasus Terrane, which was a part of the younger Cimmerian Superterrane, was linked closely to that of many other Middle Eastern terranes (Ruban et al., 2007). While the Greater Caucasus bears an affinity to the Pontides and probably the Alborz terranes, the geological history of the Lesser Caucasus was more linked to that of Central Iran and the Taurides.

7.2. Jurassic geodynamic reconstructions

Three Jurassic geodynamic reconstructions (for the Late Toarcian, the Early Bajocian, and the Middle Oxfordian) are constrained on the basis of a careful investigation of data from all Caucasian areas (Ruban, 2006c). Despite minor contrary details, they allow two very important conclusions. The first one concerns an arc-arc collision in the Middle Jurassic. There is evidence for a joining of the Northern and Southern Transcaucasian arcs since at least the Bajocian. This tectonic event may explain the mid-Jurassic major unconformity (Ruban, 2007b) and also shed light on a poorly defined mid-Jurassic orogeny hypothesized earlier, but which has remained unexplained. My reconstructions indicate the presence of a large Caucasian Sea connected with the Neotethys Ocean in the south and other seas to the west and the east by long seaways. This provides a much needed clue to explain the style of the biotic evolution in the Caucasus and its possible relationships to that in Europe and the Middle East.

7.3. Phanerozoic phases of the tectonic evolution of the Greater Caucasus

An overall examination of geological data from the Greater Caucasus permitted the identification of 7 phases in its tectonic evolution, namely the Gondwanan Phase (Cambrian-Ludlow), the Hunic Phase (Ludlow-Devonian), the Proto-Alpine Phase (Carboniferous-Middle Triassic), the Left-Shear Phase (Late Triassic-Earliest Jurassic), the Arc Phase (Jurassic-Eocene), the Paratethyan Phase (Oligocene-Miocene), and the Transcaucasus Phase (Pliocene-Recent) (Tawadros et al., 2006). These phases are also compared with those established in the Northeastern African basins in order to reveal some similar patterns, which

permits one to outline some new perspectives for hydrocarbon exploration in the Greater Caucasus (Tawadros et al., 2006).

8. Concluding remarks

The attempted study in this thesis permits me to bring the understanding of the Phanerozoic history of the Caucasus and some adjacent areas to a new level of complexity. Stratigraphic constraints strengthen the precision of all further interpretations. An analysis of fossil diversity reveals the regional appearance of mass extinctions and other crises. An interpretation of the sea-level changes allows explanation of the regional biotic and entire geological evolution in the light of transgressions, regressions, and changes in basin depth. Tectonic constraints help to understand how all regional data can be interpreted in the context of the entire northern Paleo- (and Neotethyan) margin, and which inter-regional correlations seem to be the most promising. Thus, all these studies contribute to a comprehensive synthesis of the Phanerozoic environmental changes in the Caucasus and adjacent areas.

Acknowledgements

I gratefully thank Prof. P.G. Eriksson (South Africa) for his kind supervision, support, and a lot of help. I appreciate fruitful discussions and the valuable help of M.I. Al-Husseini (Bahrain), J. Aller (Spain), M. Bécaud (France), A.J. Boucot (USA), C.P. Conrad (USA), P.V. Dolmatov (Russia), M.A. Efendiyeva (Azerbaijan), Ja.M. Gutak (Russia), W. Heckendorn (Switzerland), Y. Iwasaki (USA), A.H. Jahren (USA), N.M.M. Janssen (Netherlands), P.D. Kruse (Australia), K.B. Oheim (USA), V.I. Pugatchev (Russia), G. Racki (Poland), W. Riegraf (Germany), R. Smosna (USA), H. Sulser (Switzerland), C.S. Swezey (USA), E.E. Tawadros (Canada), J. Tyszka (Poland), A.J. van Loon (Netherlands/Poland), G.D. Webster (USA), P.B. Wignall (UK), W. Yang (USA), S. Yoshioka (Japan), A.M. Zavattieri (Argentina), H. Zerkass (Brazil), S.O. Zorina (Russia), and many others. Useful suggestions from all reviewers and editors of my papers included in this thesis are highly appreciated. Special thanks are addressed to my parents, who always support my studies.

Publications included in the present thesis

- Ruban, D.A. 2004. Diversity dynamics of Early-Middle Jurassic brachiopods of Caucasus, and the Pliensbachian-Toarcian mass extinction. *Acta Palaeontologica Polonica*. 49: 275-282.
(*keywords: brachiopods, diversity, mass extinction, Jurassic, Caucasus*)
- Ruban, D.A. 2005a. The Upper Miocene of the Rostov Dome (Eastern Paratethys): Implication of the chronostratigraphy and bivalvia-based biostratigraphy. *Geološki anali Balkanskoga poluostrva*. 66: 9-15.
(*keywords: regional stages, biozones, bivalves, Upper Miocene, Eastern Paratethys*)
- Ruban, D.A. 2005b. Mesozoic marine fossil diversity and mass extinctions: an experience with the middle XIX century paleontological data. *Revue de Paléobiologie*. 24: 287-290.
(*keywords: diversity, mass extinction, catastrophism, Mesozoic*)
- Ruban, D.A. & Tyszka, J. 2005. Diversity dynamics and mass extinctions of the Early-Middle Jurassic foraminifers: A record from the Northwestern Caucasus. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 222: 329-343.
(*keywords: foraminifers, diversity, origination, mass extinction, Jurassic, Caucasus*)
- Ruban, D.A. & Yoshioka, S. 2005. Late Paleozoic – Early Mesozoic Tectonic Activity within the Donbass (Russian Platform). *Trabajos de Geología*. 25: 101-104.
(*keywords: shear zone, Paleozoic, Mesozoic, Donbass*)
- Ruban, D.A. 2006a. Diversity changes of the Brachiopods in the Northern Caucasus: a brief overview. *Acta Geologica Hungarica*. 49: 57-71.
(*keywords: brachiopods, diversity, mass extinction, reef, Paleozoic, Mesozoic, Caucasus*)

- Ruban, D.A. 2006b. Diversity dynamics of the Triassic marine biota in the Western Caucasus (Russia): A quantitative estimation and a comparison with the global patterns. *Revue de Paléobiologie*. 25: 699-708.
(*keywords: diversity, ammonoids, bivalves, brachiopods, foraminifers, Triassic, Caucasus*)
- Ruban, D.A. 2006c. The Palaeogeographic Outlines of the Caucasus in the Jurassic: The Caucasian Sea and the Neotethys Ocean. *Geološki anali Balkanskoga poluostrva*. 67: 1-11.
(*keywords: seaway, basin, arc-arc collision, Jurassic, Caucasus*)
- Ruban, D.A. 2006d. Taxonomic diversity dynamics of the Jurassic bivalves in the Caucasus: regional trends and recognition of global patterns. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 239: 63-74.
(*keywords: bivalves, diversity, mass extinction, Jurassic, Caucasus*)
- Tawadros, E., Ruban, D. & Efendiyeva, M. 2006. Evolution of NE Africa and the Greater Caucasus: Common Patterns and Petroleum Potential. The Canadian Society of Petroleum Geologists, the Canadian Society of Exploration Geophysicists, the Canadian Well Logging Society Joint Convention. May 15-18, 2006. Calgary. P. 531-538. [extended abstract]
(*keywords: terrane, shear zone, petroleum potential, NE Africa, Greater Caucasus*)
- Ruban, D.A. 2007a. Jurassic transgressions and regressions in the Caucasus (northern Neotethys Ocean) and their influences on the marine biodiversity. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 251: 422-436.
(*keywords: transgression, regression, eustasy, diversity, Jurassic, Caucasus*)
- Ruban, D.A. 2007b. Major Paleozoic-Mesozoic Unconformities in the Greater Caucasus and Their Tectonic Re-Interpretation: A Synthesis. *GeoActa*. 6: 91-102.
(*keywords: unconformity, Paleozoic, Mesozoic, Greater Caucasus*)
- Ruban, D.A. 2007c. Taxonomic diversity structure of brachiopod associations at times of the early Mesozoic crises: evidence from the Northern Caucasus, Russia (northern Neotethys Ocean). *Paleontological Research*. 11: 349-358.
(*keywords: brachiopods, diversity, Jurassic, mass extinction, Caucasus, Triassic*)
- Ruban, D.A. 2007d. Paleozoic palaeogeographic frameworks of the Greater Caucasus, a large Gondwana-derived terrane: consequences from the new tectonic model. *Natura Nascosta*. 34: 16-27.
(*keywords: palaeogeography, terrane, carbonate platform, Paleozoic, Greater Caucasus*)
- Ruban, D.A. 2007e. Late Paleozoic Transgressions in the Greater Caucasus (Hun Superterrane, Northern Palaeotethys): Global Eustatic Control. *Cadernos do Laboratorio Xeolóxico de Laxe*. 2007. 32: 13-24.
(*keywords: palaeogeography, Late Paleozoic, sea level, eustasy, Greater Caucasus*)
- Ruban, D.A. 2007f. The southwestern margin of Baltica in the Paleozoic-early Mesozoic: Its global context and North American analogue. *Natura Nascosta*. 35: 24-35.
(*keywords: shear zone, Baltica, North America, Paleozoic, Mesozoic*)
- Ruban, D.A., Al-Husseini, M.I. & Iwasaki, Y., 2007. Review of Middle East Paleozoic Plate Tectonics. *GeoArabia*. 12: 35-56.
(*keywords: terrane, Gondwana, Arabian Plate, Middle East*)
- Ruban, D.A. 2008. Evolutionary rates of the Triassic marine macrofauna and sea-level changes: evidences from the Northwestern Caucasus, Northern Neotethys (Russia). *Palaeoworld*. 17: 115-125.
(*keywords: evolutionary rate, macrofauna, sea level, Triassic, Caucasus*)
- Ruban, D.A. & van Loon, A.J. 2008. Possible pitfalls in the procedure for paleobiodiversity-dynamics analysis. *Geologos*. 14: 37-50.
(*keywords: diversity, extinction, Lazarus taxa*)
- Gutak, Ja.M., Tolokonnikova, Z.A. & Ruban, D.A. 2008. Bryozoan diversity in Southern Siberia at the Devonian-Carboniferous transition: new data confirm a resistivity to two mass extinctions. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 264: 93-99.
(*keywords: bryozoans, diversity, mass extinction, transgression, regression, basin depth, Southern Siberia, Paleozoic*)
- Zorina, S.O., Dzyuba, O.S., Shurygin, B.N. & Ruban, D.A. 2008. How global are the Jurassic-Cretaceous unconformities? *Terra Nova*. 20: 341-346.

(keywords: *unconformity, eustasy, correlation, Jurassic, Cretaceous*)

Suggestion of order in which papers should be read

The references are presented according to the order of subjects discussed in the summary. A relative importance of each paper for the particular subject is provided. Most of the papers, however, deal with several subjects, and these relationships can be deduced from the main text of this summary. For each subject detailed below, the papers are aligned along the course of the geologic time.

Stratigraphy

- Ruban, D.A. 2007b. Major Paleozoic-Mesozoic Unconformities in the Greater Caucasus and Their Tectonic Re-Interpretation: A Synthesis. *GeoActa*. 6: 91-102.
- Zorina, S.O., Dzyuba, O.S., Shurygin, B.N. & Ruban, D.A. 2008. How global are the Jurassic-Cretaceous unconformities? *Terra Nova*. 20: 341-346.
- Ruban, D.A. 2005a. The Upper Miocene of the Rostov Dome (Eastern Paratethys): Implication of the chronostratigraphy and bivalvia-based biostratigraphy. *Geološki anali Balkanskoga poluostrva*. 66: 9-15.

Fossil diversity

- Ruban, D.A. & van Loon, A.J. 2008. Possible pitfalls in the procedure for paleobiodiversity-dynamics analysis. *Geologos*. 14: 37-50.
- Gutak, Ja.M., Tolokonnikova, Z.A. & Ruban, D.A. 2008. Bryozoan diversity in Southern Siberia at the Devonian-Carboniferous transition: new data confirm a resistivity to two mass extinctions. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 264: 93-99.
- Ruban, D.A. 2006b. Diversity dynamics of the Triassic marine biota in the Western Caucasus (Russia): A quantitative estimation and a comparison with the global patterns. *Revue de Paléobiologie*. 25: 699-708.
- Ruban, D.A. 2006a. Diversity changes of the Brachiopods in the Northern Caucasus: a brief overview. *Acta Geologica Hungarica*. 49: 57-71.
- Ruban, D.A. 2006d. Taxonomic diversity dynamics of the Jurassic bivalves in the Caucasus: regional trends and recognition of global patterns. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 239: 63-74.

Mass extinctions

- Ruban, D.A. 2007c. Taxonomic diversity structure of brachiopod associations at times of the early Mesozoic crises: evidence from the Northern Caucasus, Russia (northern Neotethys Ocean). *Paleontological Research*. 11: 349-358.
- Ruban, D.A. 2004. Diversity dynamics of Early-Middle Jurassic brachiopods of Caucasus, and the Pliensbachian-Toarcian mass extinction. *Acta Palaeontologica Polonica*. 49: 275-282.
- Ruban, D.A. & Tyszká, J. 2005. Diversity dynamics and mass extinctions of the Early-Middle Jurassic foraminifers: A record from the Northwestern Caucasus. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 222: 329-343.
- Ruban, D.A. 2005b. Mesozoic marine fossil diversity and mass extinctions: an experience with the middle XIX century paleontological data. *Revue de Paléobiologie*. 24: 287-290.

Sea-level fluctuations

- Ruban, D.A. 2007d. Paleozoic palaeogeographic frameworks of the Greater Caucasus, a large Gondwana-derived terrane: consequences from the new tectonic model. *Natura Nascosta*. 34: 16-27.
- Ruban, D.A. 2007e. Late Paleozoic Transgressions in the Greater Caucasus (Hun Superterrane, Northern Palaeotethys): Global Eustatic Control. *Cadernos do Laboratorio Xeolóxico de Laxe*. 2007. 32: 13-24.
- Ruban, D.A. 2008. Evolutionary rates of the Triassic marine macrofauna and sea-level changes: evidences from the Northwestern Caucasus, Northern Neotethys (Russia). *Palaeoworld*. 17: 115-125.
- Ruban, D.A. 2007a. Jurassic transgressions and regressions in the Caucasus (northern Neotethys Ocean) and their influences on the marine biodiversity. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 251: 422-436.

Tectonics

- Tawadros, E., Ruban, D. & Efendiyeva, M. 2006. Evolution of NE Africa and the Greater Caucasus: Common Patterns and Petroleum Potential. The Canadian Society of Petroleum Geologists, the Canadian Society of Exploration Geophysicists, the Canadian Well Logging Society Joint Convention. May 15-18, 2006. Calgary. P. 531-538. [extended abstract]
- Ruban, D.A., Al-Husseini, M.I. & Iwasaki, Y., 2007. Review of Middle East Paleozoic Plate Tectonics. *GeoArabia*. 12: 35-56.
- Ruban, D.A. & Yoshioka, S. 2005. Late Paleozoic – Early Mesozoic Tectonic Activity within the Donbass (Russian Platform). *Trabajos de Geología*. 25: 101-104.
- Ruban, D.A. 2007f. The southwestern margin of Baltica in the Paleozoic-early Mesozoic: Its global context and North American analogue. *Natura Nascosta*. 35: 24-35.
- Ruban, D.A. 2006c. The Palaeogeographic Outlines of the Caucasus in the Jurassic: The Caucasian Sea and the Neotethys Ocean. *Geološki anali Balkanskoga poluostrva*. 67: 1-11.

General References (in main text of Summary)

- Cariou, E. & Hantzpergue, P. (Eds.). 1997. Biostratigraphie du Jurasique ouest-européen et méditerranéen: zonations parallèles et distribution des invertébrés et microfossiles. *Bulletin du Centre Recherche Elf Exploration et Production*. 17: 1-440.
- Ershov, A.V., Brunet, M.-F., Nikishin, A.M., Bolotov, S.N., Nazarevich, B.P., Korotaev, M.V. 2003. Northern Caucasus basin: thermal history and synthesis of subsidence models. *Sedimentary Geology*. 156: 95-118.
- Gamkrelidze, I.P. 1997. Terranes of the Caucasus and Adjacent Areas. *Bulletin of the Georgian Academy of Science*. 155: 75-81.
- Laz'ko, E.M. 1975. Regional geology of the USSR. Vol. 1. Nedra, Moskva. 334 pp. (in Russian)
- Nikishin A.M., Ziegler P.A., Stephenson R.A., Cloetingh S.A.P.L., Furne A.V., Fokin P.A., Ershov A.V., Bolotov S.N., Korotaev M.V., Alekseev A.S., Gorbachev V.I., Shipilov E.V., Lankreijer A., Bembinova E.Yu. & Shalimov I.V. 1996. Late Precambrian to Triassic history of the East European Craton: dynamics of sedimentary basin evolution. *Tectonophysics*. 268: 23-63.
- Rostovtsev, K.O., Agajev, V.B., Azarjan, N.R., Babajev, R.G., Beznosov, N.V., Gasanov, N.A., Zasaschvili V.I., Lomize, M.G., Paitchadze, T.A., Panov, D.I., Prosorovskaya, E.L., Sakharov, A.S., Todria, V.A., Toptchischvili, M.V., Abdulkasanzade, M.R., Avanesjan, A.S., Belenkova, V.S., Bendukidze, N.S., Vuks, V.Ja., Doludenko, M.P., Kiritchkova, A.I., Klikuschin, V.G., Krymholz, G.Ja., Romanov, G.M., Schevtchenko, T.V. 1992. *Jura Kavkaza*. Nauka, Sankt-Peterburg. 192 pp. (in Russian)

Subject index

Africa

- Northeastern - Tawadros et al., 2006
- ammonites - Ruban, 2006b, 2007a, 2008
- Arabian Plate - Ruban et al., 2007
- arc-arc collision - Ruban, 2006c, 2007b; Tawadros et al., 2006
- Baltica - Ruban, 2007f
- basin depth - Ruban, 2006b, 2006d, 2007a, 2008; Gutak et al., 2008
- belemnites - Ruban, 2007a
- bivalves - Ruban, 2004, 2005a, 2006b, 2006d, 2007a, 2008
- biozones
 - ammonite-based - Ruban, 2006c, 2007a
 - bivalve-based - Ruban, 2005a
 - foraminifer-based - Ruban & Tyszka, 2005
- biotic crisis
 - Aalenian - Ruban, 2004; Ruban & Tyszka, 2005
 - Ladinian - Ruban, 2006a, 2006b, 2007c, 2008
- brachiopods - Ruban, 2004, 2006a, 2006b, 2007a, 2007c, 2008
- bryozoans - Gutak et al., 2008

carbonate platform - Ruban, 2006c, 2006d, 2007d
catastrophism - Ruban, 2005b
Caucasian Sea - Ruban, 2006c, 2007a; Tawadros et al., 2006
coral reefs - Ruban, 2006a, 2006b, 2006c, 2007d
correlation - Ruban, 2005a, 2007a, 2007b; Zorina et al., 2008
Cretaceous - Zorina et al., 2008
diversity - Ruban, 2004, 2005b, 2006a, 2006b, 2006d, 2007a, 2007c, 2008; Ruban & Tyszka, 2005; Gutak et al., 2008; Ruban & van Loon, 2008
diversity structure - Ruban, 2007c, 2008; Ruban & Tyszka, 2005; Gutak et al., 2008
deformation phases - Ruban, 2006c, 2007b, 2007f; Ruban & Yoshioka, 2005; Ruban et al., 2007; Tawadros et al., 2006
Donbass - Ruban, 2007f; Ruban & Yoshioka, 2005
Eastern Paratethys - Ruban, 2005a
eustasy - Ruban, 2007a, 2007e, 2008; Zorina et al., 2008
evolutionary rate - Ruban, 2007c, 2008
extinction - Ruban, 2004, 2006d, 2007a; Ruban & Tyszka, 2005; Ruban & van Loon, 2008
facies analysis - Ruban, 2006c, 2006d, 2007a, 2007b, 2007d, 2007e, 2008
foraminifers - Ruban, 2006b; Ruban & Tyszka, 2005
Gondwana - Ruban, 2007b, 2007d; Ruban & Yoshioka, 2005; Ruban et al., 2007; Tawadros et al., 2006
Greater Caucasus - Ruban, 2004, 2006a, 2006b, 2006c, 2006d, 2007a, 2007b, 2007c, 2007d, 2007e, 2008; Ruban & Tyszka, 2005; Tawadros et al., 2006; Ruban et al., 2007; Zorina et al., 2008
Jurassic - Ruban, 2004, 2006a, 2006b, 2006c, 2006d, 2007a, 2007c; Ruban & Tyszka, 2005; Tawadros et al., 2006; Zorina et al., 2008
Laba-Malka area - Ruban, 2004; Ruban & Tyszka, 2005
Lazarus taxa - Ruban & Tyszka, 2005; Ruban & van Loon, 2008
Lesser Caucasus - Ruban, 2006c, 2006d, 2007a; Ruban et al., 2007
macrofauna - Ruban, 2005b, 2006b, 2007a, 2008
mass extinction
---Frasnian/Famennian - Ruban, 2006a; Gutak et al., 2008
---Jurassic/Cretaceous - Ruban, 2005b, 2006a
---Permian/Triassic - Ruban, 2006a, 2007c, 2008
---Pliensbachian/Toarcian - Ruban, 2004, 2005b, 2006a, 2006d, 2007c; Ruban & Tyszka, 2005
---Triassic/Jurassic - 2007c
Mesozoic - Ruban, 2005b; Zorina et al., 2008
Middle East - Ruban et al., 2007;
Miocene
---Upper - Ruban, 2005a
North America - 2007f
origination - Ruban, 2004, 2006d; Ruban & Tyszka, 2005; Ruban & van Loon, 2008
oxygen depletion - Ruban, 2004, 2006d; Ruban & Tyszka, 2005
paleogeography - Ruban, 2006c, 2006d, 2007d; Tawadros et al., 2006
Paleozoic - Ruban, 2006a, 2007b, 2007d, 2007e, 2007f; Ruban & Yoshioka, 2005; Ruban et al., 2007; Tawadros et al., 2006
petroleum potential - Tawadros et al., 2006
plate tectonics - Ruban, 2006c, 2007b, 2007d, 2007f; Ruban & Yoshioka, 2005; Ruban et al., 2007; Tawadros et al., 2006
regional stage - Ruban, 2005a
regression - Ruban, 2006a, 2006d, 2007a, 2007d, 2008; Gutak et al., 2008
Rostov Dome - Ruban, 2005a
Russian Platform - Ruban, 2007f; Ruban & Yoshioka, 2005; Zorina et al., 2008
salinity crisis - Ruban, 2006a, 2006d
sea level - Ruban, 2004, 2006a, 2007a, 2007e, 2008; Ruban & Tyszka, 2005; Zorina et al., 2008
seaway - Ruban, 2006c

shear zone - Ruban, 2007b, 2007d, 2007f; Ruban & Yoshioka, 2005; Tawadros et al., 2006; Ruban et al., 2007
Southern Siberia - Gutak et al., 2008
terrane - Ruban, 2007b, 2007d, 2007f; Ruban & Yoshioka, 2005; Ruban et al., 2007; Tawadros et al., 2006
transgression
---Late Paleozoic - Ruban, 2007d, 2007e; Gutak et al., 2008
---Triassic - Ruban, 2008
---Jurassic - Ruban, 2006a, 2006d, 2007a
Triassic - Ruban, 2006a, 2006b, 2007c, 2007f; Tawadros et al., 2006
faunal turnover - Ruban, 2006d, 2007c; Ruban & Tyszka, 2005; Gutak et al., 2008
unconformity
---global - Zorina et al., 2008
---major regional - Ruban, 2007b