

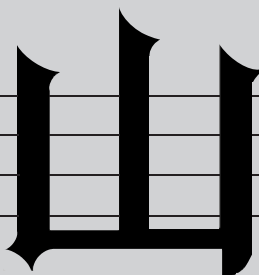
NEWSLETTER ON CARBONIFEROUS STRATIGRAPHY

Volume 24

July 2006

Correlation of major cyclothems across Moscovian-Kasimovian & Kasimovian-Gzhelian boundaries

MIDCONTINENT BASIN	MOSCOW BASIN	DONETS BASIN	Conodont first appearances
Lecompton (Queen Hill)	Amerevo	P1	<i>St. ruzhencevi</i> , <i>St. vitali</i>
Oread (Heebner)	Upper Rusavkino	O7	<i>I. simulator</i> [ss] [prob. K-G Bdy]
Cass (Little Pawnee)	Lower Rusavkino	O6/1	<i>Streptognathodus zethus</i>
Stanton (Eudora)	Troshkovo	O5	<i>Idiognathodus</i> aff. <i>simulator</i>
Iola (Muncie Creek)	Presnya	O4/3	
Dewey (Quivira)	Mestsherino	O4/1	
Dennis (Stark)	Upper Neverovo	O2	<i>Streptognathodus confragus</i>
Swope (Hushpuckney)	Mid-Neverovo	O1	<i>Streptognathodus cancellosus</i>
Hertha (Mound City)	Lower Neverovo	N5/1	
Exline	Basal Neverovo	N5	<i>Idiognathodus eccentricus</i>
Lost Branch (Nuyaka Ck.)	Voskresensk	N3/3	<i>Swadelina</i> spp.
Altamont (Lake Neosho)	Suvorovo	N3/1	<i>Swadelina</i> spp.
Lower Pawnee (Anna)	Middle Peski	N2 [?]	<i>I. delicatus</i> -like forms [also lower]



SCCS

I.U.G.S. SUBCOMMISSION ON CARBONIFEROUS STRATIGRAPHY

Table of Contents

CHAIRMAN'S COLUMN	1
SECRETARY / EDITOR'S REPORT 2005-2006	1
SCCS ANNUAL REPORT 2005	2
TASK/PROJECT GROUP REPORTS	5
Report of the Task Group seeking a GSSP close to the traditional Tournaisian-Viséan boundary.....	5
The Viséan-Serpukhovian boundary: Summary of progress made during 2005 and plans for 2006.....	5
Report of the Task Group to establish a GSSP close to the existing Bashkirian-Moscovian boundary	6
Report of the Task Group to establish the Moscovian-Kasimovian and Kasimovian-Gzhelian boundaries	8
CONTRIBUTIONS BY MEMBERS	9
The Dombar Limestone in the South Urals and the Viséan-Serpukhovian boundary (Kulagina et al.)	9
Succession and correlation of the Viséan floras of the equatorial belt (Mosseichik and Ignatiev).....	11
Pennsylvanian fern taxonomy: New approach through the compact model (Pšenička and Zodrow)	16
Discovery of potential Bashkirian-Moscovian boundary marker conodont <i>Declinognathodus donetzianus</i> in South Urals (Pazukhin et al.).....	18
Fusulinoida of the Kasimovian-Gzhelian transition in the northern Timan (Remizova)	20
Potential candidate for GSSP to define base of Gzhelian Stage in global chronostratigraphic scale: Usolka section, southern Urals, Russia (Chernykh et al.)	23
Conodont and ammonoid distribution across position of proposed Kasimovian-Gzhelian boundary in lower Virgilian strata in North American Midcontinent (Boardman et al.).....	29
Latest calibration of Middle to Late Pennsylvanian time scale using succession of Midcontinent cyclothems (Heckel)	35
Kasimovian and Gzhelian (Upper Pennsylvanian) conodont zonation in Russia (Alekseev and Goreva).....	40
SCCS VOTING & CORRESPONDING MEMBERSHIP 2006	44
SCCS OFFICERS AND VOTING MEMBERS 2004-2008	53

Newsletter on Carboniferous Stratigraphy

Edited by D.M. Work

IUGS SUBCOMMISSION ON CARBONIFEROUS STRATIGRAPHY / VOL. 24 - 2006

CHAIRMAN'S COLUMN

This past year has seen more progress in the selection of stage boundaries, as detailed in the individual reports that follow. The GSSP proposal for the Tournaisian-Viséan boundary is being adjusted prior to submission for the Subcommission vote. The Viséan-Serpukhovian Boundary Task Group is focusing on the conodont lineage *Lochriea nodosa* – *Lochriea ziegleri*, which is fairly widely distributed across Eurasia. A potential candidate section for the GSSP reported by Russian workers from the eastern slope of the southern Urals in 2005 is undergoing further detailed study. In addition, several workers are studying various sections across the boundary interval in North America to search for other biostratigraphically useful fossils and to acquire C-isotope data, in order to try to bracket the boundary there in case the *Lochriea* lineage is not discovered. The Bashkirian-Moscovian Boundary Task Group continues more detailed investigation of two conodont lineages, involving the first appearances of *Idiognathodus postsulcatus* and *Declinognathodus donetzianus*. Discovery of a new section with the latter taxon beyond its previously known limits has been reported from the southern Urals. The combined Moscovian-Kasimovian and Kasimovian-Gzhelian Boundary Task Group is examining more closely the taxonomy involved in the conodont lineages that appear useful for boundary recognition, utilizing the correlation charts across both boundaries that are based on the scales of glacial-eustatic cyclothems plus conodont and fusuline biostratigraphy, published in the 2005 Newsletter. Consensus is being reached that the first appearance of the conodont *Idiognathodus simulator* [sensu stricto] is the best marker event for the Kasimovian-Gzhelian boundary, as it is common in both Eurasia and North America. A possible candidate section for its GSSP will be further investigated in the southern Urals, where slope deposits may have been continually below the ancient level of shelves where disconformity-bounded cyclothems dominate the succession.

ICCP 2007: XVI International Carboniferous-Permian Congress in Nanjing

The 2007 XVI International Carboniferous-Permian Congress is scheduled for June 21-24 in Nanjing, China, with 4 pre-Congress and 5 post-Congress field trips planned. Please visit the excellent website at: www.iccp2007.cn for more information, and note the important deadlines for various activities that are listed on the first page. We plan to have an SCCS meeting at the Congress, and I encourage all of the task groups to have working meetings there, like those that were so successful at the Utrecht Congress in 2003.

SCCS Newsletter Funding

The serious problem that I described last year regarding the funding for printing and distributing this Newsletter has been partially alleviated by an increase in contributions from several

additional generous members than previously, for which I am very grateful. However, we are still facing a potential shortfall in funding for future publication of the Newsletter. Therefore, I again strongly urge all those of you who are able, to make as generous a donation as you can afford, in order to ensure the continuing publication of the Newsletter. Please use the form that is inserted into the Newsletter, for making your donation. Thank you very much.

Philip H. Heckel

June, 2006

SECRETARY / EDITOR'S REPORT

2004-2005

I want to thank all who provided articles for inclusion in Volume 24 of the Newsletter on Carboniferous Stratigraphy and those who assisted in its preparation. I am indebted to P. H. Heckel for editorial assistance; and to P. Thorson Work for coordinating the compilation of this issue.

Future Issues of Newsletter on Carboniferous Stratigraphy

Next year's Volume 25 will be finalized by July 2007, and I request that all manuscripts be sent before May 31—but preferably earlier. Please read the section below (page 4) regarding submission format, especially manuscript length (no more than 5 double-spaced manuscript pages without prior approval). Finally, I would be most grateful if all voting and corresponding members of the SCCS would let me know of any changes to their mailing and e-mail addresses so that we can update our records.

David M. Work

SCCS ANNUAL REPORT 2005

Membership

The Subcommittee had 21 voting members in 2005 [see list at end of Newsletter]. In addition, corresponding membership at the time of publication stands at 291 persons and 7 libraries.

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Task and Exploratory Project Groups

Task Group to establish the Tournaisian-Viséan boundary [which is also the base of the Middle Series of the Mississippian Subsystem], chaired by George Sevastopulo (Ireland).

Task Group to establish the Viséan-Serpukhovian boundary [which is also the base of the Upper Series of the Mississippian Subsystem], chaired by Barry Richards (Canada).

Task Group to establish the Bashkirian-Moscovian boundary [which is also the base of the Middle Series of the

Pennsylvanian Subsystem], chaired by John Groves (USA).

Task Group to establish the Moscovian-Kasimovian boundary [which is also the base of the Upper Series of the Pennsylvanian Subsystem], chaired by Elisa Villa (Spain). This group is also dealing with the **Kasimovian-Gzhelian boundary** within the Upper Series of the Pennsylvanian Subsystem.

Project Group on Upper Paleozoic boreal biota, stratigraphy and biogeography, chaired by Marina Durante (Russia).

Project Group on Carboniferous magnetostratigraphy, chaired by Mark Hounslow (United Kingdom).

Chief Accomplishments in 2005

Work on the Viséan-Serpukhovian, Bashkirian-Moscovian, Moscovian-Kasimovian, and Kasimovian-Gzhelian boundaries has reached the point where the several informal proposals on event markers for those boundaries that were submitted by members to the task groups in 2004 have been narrowed down to one or two lineages, mostly among conodonts. The remaining proposals are now under intensive discussion and have engendered much further research in several areas on the lineages and also on potential candidates for GSSPs for two of the boundaries.

The Newsletter on Carboniferous Stratigraphy, Volume 23, published in July 2005, contains reports of the task groups for 2004-5 and 12 articles on various topics of interest, including: Correlation of the base of the Viséan Stage in the type Mississippian region of North America; Report of the first meeting on Upper Paleozoic chronostratigraphy of South America; An essay on the necessity of regional stages in Gondwana; A report on the new German Carboniferous correlation table; Bivalve biostratigraphy of the Kulm Facies in central Europe; Sediments and fauna across the Tournaisian-Viséan

boundary in southern Tien Shan in Kyrgyzstan; Viséan-Serpukhovian transition in the Middle Tien Shan; Advances in correlation of the Viséan-Serpukhovian boundary in the South Urals; Correlation of Viséan plant-bearing deposits on the Russian Platform; Geography and succession of Viséan European floras; Cyclothem correlation and biostratigraphy across the Moscovian-Kasimovian and Kasimovian-Gzhelian boundaries in North America and Eurasia; and Lower Kasimovian correlation at Donskaya Luka in southern Russia, for a total of 70 pages.

Work Plan for 2006 and Following Years

The SCCS held a meeting on May 24, 2005, at the University of Liege, Belgium, followed by a field trip to the type Dinantian [Tournaisian-Viséan] region in the Meuse River valley of southern Belgium. The SCCS is looking forward to the planned XVI International Carboniferous-Permian Congress in Nanjing, China, in late June of 2007, where there will be meetings of the task groups as well as the traditional meeting of the SCCS.

Tournaisian-Viséan boundary. This task group internally approved the proposal to select the GSSP at the Pengchong section in southern China, and is now adjusting the final details in the formal proposal for a late 2006 SCCS ballot on the GSSP.

Viséan-Serpukhovian boundary. This task group is now working with the conodont lineage *Lochriea nodosa* – *Lochriea zieglerei* as a potential boundary-defining event. It is focusing work on other biostratigraphically useful fossils across the boundary in areas where this lineage is not yet found, and on evaluating information from a potential GSSP section in the eastern slope of the southern Urals that was presented at the May 2005 Liege meeting.

Bashkirian-Moscovian boundary.

This task group is now focusing on the work needed to evaluate the proposals it received in 2004 for boundary-defining events in several conodont lineages, particularly those involving the first appearances of *Idiognathoides postsulcatus* and *Declinognathodus donetzianus*.

Moscovian-Kasimovian boundary.

This task group will meet in Ljubljana, Slovenia, in August 2006, to further discuss the cyclothem-based correlation chart of strata across this boundary interval as a basis for evaluating the conodont and fusuline lineages proposed as boundary-defining events, along with the taxonomic issues involved in these lineages across the boundary interval.

Kasimovian-Gzhelian boundary.

The same task group will discuss the possible conodont lineages leading to *Idiognathodus simulator* [sensu stricto], which is largely agreed upon as the boundary-defining event. Recent taxonomic work on this lineage from different areas will be presented at the Ljubljana meeting in August 2006. A late 2006 ballot is anticipated on the boundary-defining event.

Progress appears to have been sufficient in all task groups, such that the selection of the boundary-defining events for all the remaining stage boundaries in the Carboniferous is realistic by the ICS deadline of 2008. However, the strong glacial-eustatic control over sedimentation that resulted in widespread

exposure surfaces across entire shelves during the time spanning at least the upper two boundaries is hampering the identification of potentially acceptable GSSPs, although a possible candidate GSSP for the highest boundary is being further investigated. The Project Group on Carboniferous Magnetostratigraphy has been focusing on supplementing the pan-tropical biostratigraphic framework, and eventually hopes to help integrate the tropical plant-rich terrestrial succession and the more polar fossil assemblages into the marine pan-tropical Carboniferous time scale. Increasingly precise ID-TIMS measurements of U-Pb zircon ages of volcanic tuff beds in the southern Urals indicate progress in dating biostratigraphically constrained successions across important boundaries.

STATEMENT OF OPERATING ACCOUNTS FOR 2004/2005

Prepared by David Work, Secretary

(Definitive accounts maintained in US currency)

INCOME (Oct. 31, 2004 – Oct. 31, 2005)

IUGS-ICS Grant 2005	\$750.00
Donations from Members	345.00
Interest	<u>6.32</u>
TOTAL INCOME	\$1101.32

EXPENDITURE

Newsletter 23 (printing)	\$645.60
Postage for bulk mailings	470.05
Mailing/Office Supplies	90.90
Bank Charges	<u>120.00</u>
TOTAL EXPENDITURE	\$1326.55

BALANCE SHEET (2004 – 2005)

Funds carried forward from 2003 – 2004	\$1754.74
PLUS Income 2004 – 2005	1101.32
LESS Expenditure 2004 – 2005	<u>-1326.55</u>

CREDIT balance carried forward to 2006

\$1529.51

Donations in 2005/2006:

Publication of the Newsletter on Carboniferous Stratigraphy is made possible with generous donations received from members/institutes during 2005-2006 and anonymous donations, combined with an IUGS subsidy of US \$750 in 2005, and additional support from a small group of members who provide internal postal charges for the Newsletter within their respective geographic regions.

W. R. Danner, R. Gastaldo, E. Grossman, P. H. Heckel, J. Kullmann, M. Menning, C. A. Ross, J. R. P. Ross, C. A. Sandberg, W. B. Saunders, G. D. Webster, R. R. West, T. E. Yancey, and 5 anonymous donors.

COVER ILLUSTRATION

Correlation of late Middle through mid-Late Pennsylvanian major cyclothems in areas where they are recognized in North America and eastern Europe, across levels being considered for global Moscovian-Kasimovian and Kasimovian-Gzhelian boundaries, summarized and slightly revised by P. H. Heckel from detailed diagrams in 2005 article by Heckel and 13 others in Newsletter on Carboniferous Stratigraphy, v. 23, p. 36-44.

Gray shading shows areas where first (and in one case continuing higher) appearances of indicated conodont taxa are reported from that particular cyclothem level. Cyclothems classified as major in North America because of widespread extent, deep-water facies, and conodont abundance are shown in boldface. Exline cyclothem is classified as intermediate in scale, but is included here because it contains first appearance of *Idiognathodus eccentricus*, which defines regional Missourian-Virgilian boundary in North America. Correlative cyclothems in eastern Europe that are considered major in those areas are also shown in boldface.

Although general consensus exists for defining Kasimovian-Gzhelian boundary at first appearance of *Idiognathodus simulator* [sensu stricto] in Oread—Upper Rusavkino—O7 cyclothem, no consensus yet exists for level of Moscovian-Kasimovian boundary, which currently is placed at base of Suvorovo Formation in Moscow Basin, based on fusuline data.

CONTRIBUTIONS TO THE NEWSLETTER

The Newsletter on Carboniferous Stratigraphy is published annually (in July) by SCCS. It is composed of written contributions from its members and provides a forum for short, relevant articles such as:

- *reports on work in progress and / or reports on activities in your work place
- *news items, conference notices, new publications, reviews, letters, comments
- *graphics suitable for black and white publication.

Contributions for each issue of the Carboniferous Newsletter should be timed to reach the Editor before 31 May in the year of publication. It is best to submit manuscripts as attachments to Email messages. Except for very short news items, please send messages and manuscripts to my Email address. Manuscripts may also be sent to the address below on CD prepared with **Microsoft Word (preferred)** or WordPerfect but any common word processing software or plain ASCII text file can usually be accommodated. Word processing files should have no personalized fonts or other code. Maps and other illustrations are acceptable in tif, jpeg, eps, or bitmap format. If only hard copies are sent, these must be camera-ready, i.e., clean copies, ready for publication. Typewritten contributions may be submitted by mail as clean paper copies; these must arrive well ahead of the deadline, as they require greater processing time.

Due to the recent increase in articles submitted by members we ask that authors limit manuscripts to 5 double-spaced pages and 1 or 2 diagrams, well planned for economic use of space.

Please send contributions as follows,

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Report of the Task Group seeking a GSSP close to the traditional Tournaisian-Viséan boundary.

George Sevastopulo and Task Group

Department of Geology, Trinity College, Dublin 2, Ireland.

The work of the group is almost complete. F.-X. Devuyst and Jiri Kalvoda have finished a major revision of late Tournaisian/early Viséan *Eoparastaffella* spp., which has been accepted for publication in the Journal of Foraminiferal Research. Following a successful project to date the base of the Livian Substage in Belgium utilizing U-Pb TIMS dating of zircons, attempts will be made to date ash bands in the latest Tournaisian and early Viséan in Ireland to bracket the age of the Tournaisian-Viséan boundary. This work is being carried out by Dr. David Chew, Trinity College Dublin, in collaboration with the Geochronology Laboratory of the University of Geneva, Switzerland.

A formal proposal for the GSSP for the base of the Viséan Stage to be located in the Pengchong section, south China, as outlined in previous reports of the task group, will be presented to the SCCS this autumn for approval and transmission to the Commission on Stratigraphy of the IUGS.

The Viséan-Serpukhovian boundary: Summary of progress made during 2005 and plans for 2006

Barry C. Richards and Task Group

Geological Survey of Canada – Calgary, 3303 - 33rd St. NW, Calgary, Alberta, Canada T2L 2A7.

The process for selecting a GSSP for the base of the Serpukhovian Stage is well under way and a potential candidate section for the GSSP has been located. The task group has concluded that the first evolutionary appearance of the conodont *Lochriea ziegleri* in the lineage *Lochriea nodosa* – *Lochriea ziegleri* currently presents the best potential for boundary definition. Several members of the task group along with associate members are conducting high-resolution biostratigraphic, lithostratigraphic and stable-isotope geochemical studies across the Viséan-Serpukhovian boundary in several regions including the southern Urals (Nikolaeva et al., 2005) and Moscow Basin in Russia (Kabanov 2004), southern Peoples Republic of China (Wang and Qi, 2003), southern Rocky Mountains of southwestern Canada, and southern Nevada in the southwestern United States (Richards et al., 2005).

L. ziegleri appears near the middle of the Brigantian Substage, which is slightly below the current base of the Serpukhovian. The lineage, best documented from relatively deep-water sections, has been identified in several European sections (Nemirovskaya et al., 1994; Skompski et al., 1995). In addition, one of the task group, Qi Yu-ping, recently recognized

the lineage *L. nodosa* – *L. ziegleri* and other lineages within the *Lochriea* group of species in the Nashui section near the town of Luodian, Guizhou, southern Peoples Republic of China (Wang and Qi, 2003). In the Zaborie quarry section, *Lochriea ziegleri* appears with *Lochriea senckenbergica* in the basal bed (about 65 cm thick) of the type Serpukhovian (Nikolaeva et al., 2002), but this is not a first evolutionary appearance.

Nikolaeva et al (2005) have recognized the *L. nodosa* – *L. ziegleri* lineage in a condensed, relatively deep-water, carbonate section along the Ural River opposite the village of Verkhnyaya Kardailovka on the eastern slope of the southern Urals, southern Russia. According to Nikolaeva et al. (2005), the section is a good potential candidate section for the GSSP at the base of the Serpukhovian. During 2005, Nikolaeva and her colleagues continued work on the Kardailovka section and expanded their study of carbonate-dominated, Viséan-Serpukhovian successions to Dombar and Kyzl-Shin in the Aktyubinsk region of northern Kazakhstan. During 2006, Nikolaeva and her colleagues plan to continue work at Kardailovka and examine thick, carbonate-dominated sections at nearby Kizl and Khudolaz.

Kabanov (2004), an associate member of the task group, carefully restudied the type section of the Serpukhovian in the Zaborie quarry in the Moscow Basin, focusing on the major depositional and biostratigraphic events recorded by the lower part of the section. During 2006, Kabanov plans to sample the shale and mudstone in the Zaborie section and ship the samples to John Utting (Geological Survey of Canada-Calgary) for identification of the palynomorphs and an evaluation of their biostratigraphic potential.

To facilitate palynological correlations between North America and the upper Viséan-Serpukhovian of Russia, Utting plans to sample the Brigantian-Pendleian succession in western Newfoundland, eastern Canada for palynomorphs. Related to this work, Utting intends to process some of the numerous palynological samples that team members recently collected from formations spanning the Viséan-Serpukhovian boundary in western North America.

Recent work of team member Alan Titus on conodont assemblages in several sections of basinal facies in the Chainman Formation of western Utah and eastern Nevada suggests the recognition of the *L. nodosa* – *L. ziegleri* lineage in North America is unlikely. If we use the first evolutionary appearance of *L. ziegleri* for boundary definition, it will be necessary to use either geochemical data or other species (conodont, foraminifer or ammonoid) that appear concomitantly with the Eurasian *L. ziegleri* to achieve a precise correlation with North America. With this in mind, Alan Titus indicated that ammonoids could be used to facilitate a precise correlation between Eurasia and North America. Ammonoid-based geochronology is well developed near the level of the Viséan-Serpukhovian boundary because beds near the boundary contain numerous very distinct ammonoid morphotypes.

In October 2004, team members Titus and Richards examined several sections of the Chainman Formation in western Utah in

search of ammonoid- and conodont-bearing sections that might permit an exact correlation with Eurasian sections preserving first appearances of *Lochriea ziegleri*. A well exposed upper Viséan to lower Serpukhovian (Asbian to Pendleian) section at Jensen Wash in western Utah was considered to be the best in the region. During 2006 and 2007, team members plan to measure and sample the Jensen Wash section for ammonoids, conodonts, palynomorphs, and specimens for stable isotope (carbon and oxygen) geochemistry. In late November of 2004, shelf carbonates that are correlative with the Chainman and widely preserved in the upper Viséan and Serpukhovian Battleship Wash Formation of southern Nevada were measured and sampled for conodonts, ammonoids, and foraminifers. Team members plan to start processing the Battleship Wash samples in 2006.

Carbonate ramp lithofacies of the upper Viséan and Serpukhovian Etherington Formation were recently measured at six localities in the southern Canadian Rocky Mountains and sampled for conodonts, foraminifers, and geochemistry. A seventh section, consisting of somewhat deeper water carbonates than those in the other six sections, is currently being measured and sampled. The processing of the Etherington samples is at an early stage. During 2006 coral experts, E.W. Bamber (emeritus at Geological Survey of Canada-Calgary) and Sergio Rodregez (Ciudad Universitaria, Madrid), plan to study the rugose corals collected from the Etherington sections. In conjunction with the coral study, team member B.L. Mamet (Universite de Bruxelles, Belgium) has agreed to identify the associated foraminifers and algae in the two Etherington sections containing the most abundant and taxonomically diverse coral faunas.

From the study of the Etherington sections and those through the Chainman and Battleship Wash Formations, the working group hopes to better understand the biostratigraphy and carbon stable-isotope signature of the Brigantian and Pendleian successions in selected regions of western North America. In addition, the work provides another opportunity to look for the *L. nodosa* – *L. ziegleri* lineage in western North America.

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Report of the Task Group to establish a GSSP close to the existing Bashkirian-Moscovian boundary

John Groves and Task Group

Department of Earth Science, University of Northern Iowa,
Cedar Falls, IA 50614, USA.

Background

Our task group has evaluated three proposals for defining the base of the Moscovian Stage: 1) appearance of an advanced morphotype of *Neognathodus nataliae*; 2) appearance of *Idiognathoides postsulcatus* from *I. sulcatus*; and 3) appearance of *Declinognathodus donetzianus* from *D. marginodosus*. The first of these proposals received little support from task group members, whereas the second and third received conditional support.

It is clear that we are unlikely to find a universally acceptable marker. For example, *D. donetzianus* is easily recognized but somewhat limited in its paleogeographic distribution. *Idiognathoides postsulcatus* is slightly more widespread, but it is less easily identified and its occurrences may be diachronous from region to region. Katsumi Ueno and Tamara Nemyrovska are working to confirm the age and identification of possible Bashkirian occurrences of *I. postsulcatus* in the Omi and Akiyoshi limestones of Japan. Apparently there are no occurrences of *I. postsulcatus* in cratonic North America, in contrast to our original information.

Both *D. donetzianus* and *I. postsulcatus* appear in the K₂ limestone in the Donets Basin in close association with the appearances of the fusulinids *Eofusulina triangularis* and *Aljutovella aljutovica*. The appearance of *D. donetzianus* also closely coincides with that of *A. aljutovica* in the upper Alyutovo Formation in the Moscow Basin. It is reasonable to expect that the K₂ level (or an equivalent level elsewhere) may emerge as the basal Moscovian datum.

Given that either *D. donetzianus* or *I. postsulcatus* might be chosen as the marker and that both have limited geographic distributions, our challenge is to demonstrate how the base of the Moscovian Stage might be identified in areas where these taxa do not occur. Members of the task group have been asked to address this challenge. To date, responses have been received from specialists working in the South Urals, Spain, Turkey, northern South America, and cratonic North America.

South Urals

(summary from Elena Kulagina and Vladimir Pazukhin)

The Basu section in the South Urals contains *Declinognathodus marginodosus* and *D. donetzianus* in evolutionary continuity. Elsewhere in the region *D. marginodosus* is common but *D. donetzianus* is quite rare. The appearance of *D. donetzianus* at the Basu section is accompanied by occurrences of *D. marginodosus*, *Idiognathoides ouachitensis*, *Id. sinuatus*, *Id. tuberculatus*, *Idiognathodus aljutovens*, *Hindeodus minutus*, *Profusulinella prisca*, *P. cf. paratimanica*, *P. cf. sphaeroidea*, *P. ex gr. rhomboides*, *Schubertella gracilis*, *Neostaffella* sp., *Eostaffella*

kashirica, *Asteroarchaediscus baschkiricus*, *Neoarchaediscus probatus*, and *Archaediscus* cf. *latispiralis*. Operationally, the base of the Moscovian is approximated throughout the South Urals using appearances of *Id. ouachitensis*, *P. prisca*, *Aljutovella* ex gr. *aljutovica*, and *Schubertella gracilis*.

Cantabrian Mountains, Spain

(summary from M. L. Martínez Chacón, C. Méndez, O. Merino, R. M. Rodríguez, L. C. Sánchez de Posada, and E. Villa)

The Spanish research group has begun a detailed biostratigraphic and sedimentologic analysis of the Bashkirian-Moscovian boundary interval at the Las Llacieras section. This section is very important because the exposed strata represent platform toe-to-slope and lower slope deposits. Detrital carbonate beds, derived from upper slope, margin, and platform top sources, alternate with basinal sediments. Foraminifer-rich beds (platform-derived) and conodont-rich beds (mostly basinal) should provide a good biostratigraphic record across the Bashkirian-Moscovian transition. Preliminary results indicate that lower (but not lowest) Moscovian samples contain the conodonts *Idiognathoides sinuatus*, *Idiognathoides* n. sp. 3, *Declinognathodus marginodosus*, *Neognathodus atokaensis*, and *Diplognathodus ellesmerensis*. The samples that yielded these conodonts are overlain five meters higher by a fusuline-bearing bed with *Profusulinella prisca*, *Eofusulina* sp., *Ozawainella* sp., and *Schubertella* (= *Eoschubertella*) ex gr. *obscura*. A suite of samples that extends lower and presumably spans the boundary has been collected and will be examined later this year.

Central Taurides, Turkey

(summary from Demir Altiner)

Altiner and co-workers have undertaken an exhaustive investigation of Bashkirian-Moscovian boundary beds within the Yaricak Formation of the Aladag allochthon near the town of Hadim, Konya. Bashkirian beds are bioclastic and oolitic limestones intercalated with quartz arenites, and they contain the complete succession of fusulinoidean zones known from the Urals and Russian Platform. Beds close to the Bashkirian-Moscovian boundary are characterized by a decline in pseudostaffellids, eostaffellids, and archaediscids. Lower Moscovian strata are bioclastic and micritic limestones characterized by a proliferation of profusulinellids and aljutovellids and the appearance of the *Eofusulina*–*Paraeofusulina* complex. Despite the richness of fusulines, neither the *Verella*–*Eofusulina* evolutionary transition nor the *Tikhonovichiella*–*Aljutovella* transition provides a reliable, local basis for boundary recognition. The reason is that the two ancestral forms are rare and the appearance of *A. aljutovica* is somewhat higher than expected. The base of the Moscovian is provisionally recognized on the appearance of *Profusulinella prisca*, approximately 2–3 m below the first occurrences of the *Eofusulina*–*Paraeofusulina* complex and *A. aljutovica*.

Amazonas, Solimões, and Madre de Díos Basins (Brazil, Bolivia, and Peru)

(summary from Demir Altiner and John Groves)

Identification of the Bashkirian-Moscovian boundary in northern South America is not straightforward, as this area is more similar faunally to cratonic North America than to Eurasia. Melo et al. (1999) placed the Morrowan-Atokan boundary

in the Amazonas and Solimões Basins at the appearance of *Diplognathodus coloradoensis* in the Itaituba Formation, and they equated this level with the Bashkirian-Moscovian boundary. In fact, whereas *D. coloradoensis* is a good lower Atokan marker in cratonic North America, it occurs in basal Asatausky beds in the South Urals, a level well below the base of the Moscovian. According to Altiner, the appearance of *Profusulinella* spp. in the Amazonas and Solimões Basins may more nearly approximate the position of the Bashkirian-Moscovian boundary. Altiner further notes that certain North and South American species in *Profusulinella* (e.g., *P. decora*) may belong to the *P. prisca* plexus, which appears at or near the base of the Moscovian throughout Eurasia. Bashkirian-Moscovian strata in the Madre de Díos Basin are assigned to the lower Copacabana Formation, which contains a succession of foraminifers very similar to those of cratonic North America. In the absence of detailed conodont work on the Copacabana, the Bashkirian-Moscovian boundary may be approximated by the appearance of *Profusulinella* spp.

Cratonic North America

(summary from John Groves and Lance Lambert)

Neognathodus atokaensis has been mentioned as a possible alternative basal Moscovian index. This species first occurs in the lower to middle part of the Atoka Formation in the structurally complex type Atokan area of southern Oklahoma. At the Canyon Creek section samples containing the appearance of *N. atokaensis* also yielded *Fusulinella devexa*, indicating a late Atokan age. At the Coal Creek section *N. atokaensis* and *F. devexa* are found together again, but the appearance of *N. atokaensis* occurs ~200 feet (~65 m) lower in beds that have not produced fusulinoideans. Grayson (1984) regarded the *N. atokaensis* Assemblage Zone as middle Atokan, but he acknowledged that the biostratigraphic utility of the zone was not tested. In the South Urals *N. atokaensis* first occurs in the mid-Asatausky (upper Bashkirian), slightly higher than the appearance of *D. coloradoensis*. In the Donets Basin, *N. atokaensis* appears in the middle of the Vereian, in limestone K₆³. Thus, it seems that East European appearances of *N. atokaensis* are slightly diachronous, falling on either side of the Bashkirian-Moscovian boundary, whereas in North America the age of the oldest *N. atokaensis* is not firmly known. It is possible that the base of the Moscovian may be approximated in cratonic North America by the abrupt appearance of *Profusulinella* spp. Groves et al. (in press) suggested that earliest North American species in the genus arrived as immigrants in early Vereian time. Specifically, *P. marblensis* from the Marble Falls Limestone in central Texas is morphologically very similar to *P. prisca*, whose appearance in Eurasia falls close to the Bashkirian-Moscovian boundary.

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Report of the Task Group to establish the Moscovian-Kasimovian and Kasimovian-Gzhelian boundaries

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The Task Group to establish the Moscovian-Kasimovian and Kasimovian-Gzhelian boundaries has continued studies on fossil lineages and potential levels of correlation within the interval from the upper Moscovian into the lower Gzhelian. In August 2005, the group held a meeting with presentations, workshops, and discussions at the VSEGEI in St. Petersburg, Russia, which was organized by voting member Olga Kossovaya and was attended by task group members A. Alekseev, H. Forke, N. Goreva, P. Heckel, T. Isakova, O. Kossovaya, C. Méndez, T. Nemyrovska, S. Remizova, K. Ueno, and E. Villa. Substantial progress was made on correlation of cyclothem units across both boundaries, and on definition of the K-G boundary. The task group has generally agreed upon a rather detailed correlation of the sequence-stratigraphic units called cyclothem in the regions (Midcontinent U.S.A.; Moscow Basin; Donets Basin) where they can be recognized in strata across these boundaries, based on scale of the cyclothem in conjunction with biostratigraphy of the conodont and fusuline faunas. The biostratigraphic data also allow correlation with sections from those areas where cyclothem are not yet recognized, in the southern Urals, Cantabrian region of northern Spain, and the Carnic Alps. These correlations are shown in charts and text published by P. Heckel and 13 other task group members in the 2005 Newsletter on Carboniferous Stratigraphy, v. 23, p. 36-44.

Moscovian-Kasimovian Boundary

During the St. Petersburg meeting, the Moscovian-Kasimovian chart was refined, with new data from the classical sections (Afanasiovo in the Moscow Basin; Kalinovo in the Donets Basin; Las Llacerias in the Cantabrian Mountains) as well as new information from new sections at Donskaya Luka on the Russian Platform, more recently studied by the Moscow group. This chart will be updated for future publication.

Discussions and joint work during the meeting provided noteworthy progress in fusuline correlation between the Moscow Basin (MB) and Donets Basin (DB), which are key Eurasian sections in Pennsylvanian chronostratigraphy. Deposition in these two areas occurred under rather different environmental conditions during latest Moscovian and Kasimovian, producing different compositions of the fusuline and conodont assemblages, which had led to previous confusion in correlation. Detailed studies on additional fusuline materials shed new light on these problems and provide support for the following correlations: a) equivalence of the Upper Peski Formation (MB) and the N_3 limestone (DB) [however, this differs from the correlation in Heckel et al. (2005) based on the first appearance of the conodont *Swadelina* in the Suvorovo Formation (above the Upper Peski) and the N_3 limestone]; b) equivalence of the Voskresensk Formation (MB) and the N_3^3 limestone; c) equivalence of the

upper Neverovo Formation (MB) and the O_2 limestone (DB). It also better established the age of the O_1 limestone, which was formerly thought to be in the upper part of the *Protriticites* Zone (late Krevyakinian), but after discovery of undoubted *Montiparus*, is now assigned to the lower part of the *Montiparus* Zone (early Khamovnikian). This younger age of the O_1 limestone more closely aligns the correlations based on fusulines and conodonts.

In the search for a convenient marker, data obtained so far suggest that the most widespread taxa are conodonts occurring around a stratigraphic interval within the Hertha and Swope cyclothem in the North American Midcontinent, the lower (not basal) and middle Neverovo Formation in the Moscow Basin, and the N_5^1 and O_1 limestones in the Donets Basin. A level of correlation within that interval would raise the current position of the Moscovian-Kasimovian boundary. The most promising taxon so far may be the conodont *Idiognathodus sagittalis*, but its potential value must be confirmed after data gathered from coming studies. The Moscow group has samples from a more complete section in the Oka-Tsna swell on the Russian Platform southeast of Moscow. J. Barrick and colleagues have detailed samples across this boundary in the Big Hatchet Mountains of New Mexico. Chinese colleagues are working on the Nashui section in Guizhou (southern China), which appears to be an upper slope succession that may be more complete than many other sections, and for which general information on conodont zonation has become available. It will be necessary to clarify the phylogenetic relationships among several *I. sagittalis*-like morphotypes and to define the morphological changes within this lineage, so that *I. sagittalis* [sensu stricto] could be separated from its ancestor and its first appearance used to recognize the boundary.

Kasimovian-Gzhelian Boundary

It is generally agreed that the Kasimovian-Gzhelian boundary will be based on the occurrence of the conodont *Idiognathodus simulator*, which is known from a number of relevant sections in areas representing both the American and Eurasian paleobiogeographic provinces. This level is situated in the Oread cyclothem (Midcontinent), Finis Shale (Texas), and Shumway cyclothem (Illinois Basin) in North America, in the Upper Rusavkino Formation (Moscow Basin), O_7 limestone (Donets Basin), in eastern Europe, and in bed 46 of the Dalniy Tyulkas section, bed 4-2 of the Usolka section, and bed 7 of the Nikolsky section in the southern Urals. The proposed boundary is slightly higher than the traditional lower Gzhelian and lower Virgilian boundaries.

This correlation is reinforced in Eurasia by the appearance of the fusuline *Rauserites rossicus* at a level very close to first appearance of *I. simulator*. This fusuline has been so far reported from Moscow Basin, Samarskaya Luka and Trans-Volga region, northern Timan, Timan-Petchora, north Greenland, Donets Basin, Urals, Carnic Alps, northern Fergana, Darvas, and the Cantabrian Mountains. Therefore, *Rauserites rossicus* may be a tool of prime importance for correlation within Eurasia in conjunction with *Idiognathodus simulator*. However, two possible morphotypes seem to exist within the *Rauserites rossicus* plexus: one of them (morphotype A) is older than the other (morphotype B),

and only the latter is coincident with the new position of the Kasimovian-Gzhelian boundary. This idea needs to be confirmed through further studies and revision of the available collections of *Rauserites rossicus* specimens.

Coming Steps

To continue discussions and laboratory workshops, the group will meet again in Ljubljana, Slovenia, from August 2-6, 2006.

Matevz Novak, from the Geological Survey of Slovenia, has kindly agreed to organize and to chair it. Prior to the meeting, the task group will carry out a field trip to relevant sections in the Carnic Alps (led by Dr. Holger Forke, in cooperation with Prof. Hans-Peter Schönlaub, Geological Survey of Austria, and Dr. Elias Samankassou, University of Fribourg, Switzerland), and to Karavanke Mountains (guided by Matevz Novak and Dr. Holger Forke).

CONTRIBUTIONS BY MEMBERS

Views and interpretations expressed / presented in contributions by members are those of individual authors / co-authors and are not necessarily those of the SCCS and carry no formal SCCS endorsement.

The Dombar Limestone in the South Urals and the Viséan-Serpukhovian boundary

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The South Urals contain world-famous localities for Carboniferous ammonoids. Upper Viséan and Serpukhovian shallow-water carbonates from this region were studied by Ruzhencev and Bogoslovskaya (1971) who named them the Dombar Limestone. The outcrops of the Dombar Limestone extend as an interrupted band in the meridional direction for over 50 km and are exposed along the Kiya, Dombar, Alabaital, Zhaksy-Kargaly, Shandy, and Sholak-Sai Rivers, within the Kiya-Shandy region of the Central Uralian Tectonic Zone (Fig. 1). Everywhere in this region the Dombar Limestone overlies the Viséan Chanchar Shale (Khvorova, 1961) and is strongly tectonically dislocated. Ammonoids are extremely abundant in all the above localities and they form the basis for the Viséan-Serpukhovian ammonoid biostratigraphy of the South Urals. The ammonoid genozones established in this region have been used in all Russian Carboniferous stratigraphic schemes.

However, until recently, the exact position of the ammonoids in the sections has not been recorded, while correlation of ammonoid genozones with zones based on other groups, particularly conodonts, has not been precisely established. In 2005, a joint group of scientists from Moscow, Ufa, and Aktobe organized a field trip to western Kazakhstan (Kyzyl-Shin, Alabaital, and Zhaksy-Kargaly) to resample the ammonoid-bearing sections in order to refine correlations between zonations based on different fossil groups. In the studied sections the Upper Viséan and Serpukhovian are represented by light-gray, thickly-bedded limestone and crinoidal limestone, usually

alternating with the beds of ammonoid-bearing limestone. Other associated fossil groups include ostracodes, gastropods, bivalves, and conodonts. Microscopic study has shown the fossil-bearing units are composed of micritic limestone (mudstone and wackestone).

The geochronologically oldest beds occur in the north of the region (along the Kyzyl-Shin River; basin of the Kiya River) where the Upper Viséan *Beyrichoceras*–*Goniaticeras* ammonoid Genozone was originally established. The carbonates in this section are slightly over 10 m thick. The basal layers of the section contain a bed with oncolites, and the upper part contains a bivalve shellstone bed.

Younger beds are exposed in a section along the Kiya River (Orenburg Region) which includes the Upper Viséan *Hypergoniatites*–*Ferganoceras* Genozone and the Serpukhovian *Uralopronorites*–*Cravenoceras* and *Fayettevillea*–*Delepinoceras* Genozones. The Kiya section also contains foraminifers, ostracodes, and conodonts of the *Lochriea nodosa*, *L. ziegleri* and *Gnathodus bilineatus bollandenis* Zones (Kulagina et al., 1992). The foraminiferal assemblage is very poor (*Asteroarchaediscus rugosus*, *Planospirodiscus taimyricus*, and *Monotaxinoides priscus*). Ostracode assemblages include numerous *Acratia* sp. and *Bohlinatia* sp.

Several outcrops have been examined in the region of the Alabaital River (Dombar Hills). The Dombar-2 section is particularly important for discussions of the Viséan-Serpukhovian boundary problem since the boundary between the uppermost Viséan *Hypergoniatites*–*Ferganoceras* Genozone and the lowermost Serpukhovian *Uralopronorites*–*Cravenoceras* Genozone has been recorded here (Fig. 2). Our sample 114 is equivalent to Sample 14 of Ruzhencev and Bogoslovskaya (1971), and our sample 108 is equivalent to Sample 8 of Ruzhencev and Bogoslovskaya (1971). The boundary interval is less than 7 m thick and is composed of bedded crinoidal limestone with micritic cement, with numerous ammonoid shells. Ammonoid assemblages are very rich (see Fig. 2). Conodonts in the Upper Viséan part of the section include *Lochriea nodosa*, *L. commutata*, *L. ziegleri*, *Gnathodus girtyi girtyi*, *Gn. bilineatus bilineatus*, *Pseudognathodus homopnuctatus*, and *L. mononodosa*. In the Serpukhovian part, the conodont assemblage includes *L. nodosa*, *L. ziegleri*, *L. cruciformis*, *L. commutata*, *Gnathodus bilineatus*

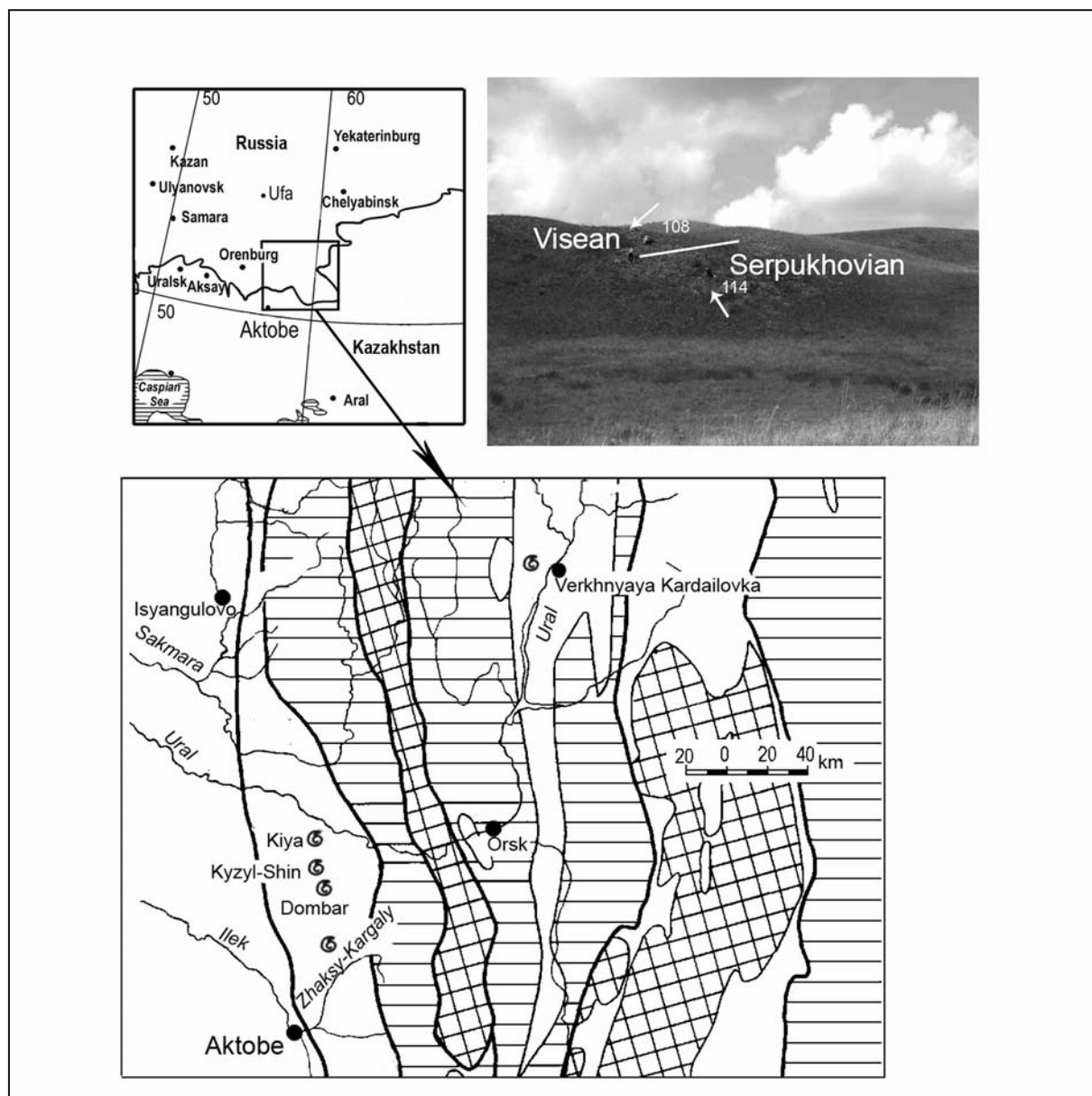


Figure 1. Ammonoid localities in the South Urals. The photograph shows the position of Visean-Serpukhovian boundary beds in the Dombar-2 section.

bilineatus, and *Gn. girtyi girtyi*. A detailed analysis of the distribution of ammonoids and conodonts across this boundary is currently being prepared for publication. The Dombar-2 section also contains gastropods and ostracodes (large *Praepilatina* sp. and numerous *Bolbozoella nodosa*). The lithology and fauna of the Dombar Hills sections suggest a shallow-water, semi-isolated basin densely populated by crinoids and ammonoids.

To the south of the Dombar Hills, on the left bank of the Zhaksy-Kargaly River, a 10 m thick section representing the Lower Serpukhovian *Uralopronorites*–*Cravenoceras* Genozone is exposed. This section also contains brachiopods and ostracodes (*Carbonita subquadrata* Zone).

Ammonoid-bearing carbonates of similar age have also been recorded further north, on the eastern slope of the South Urals, on the left bank of the Ural River opposite the village of Verkhnyaya Kardailovka (Bashkortostan). The Verkhnyaya Kardailovka

and Dombar sections are both relatively thin and both consist predominantly of micritic limestones with ammonoids. However, the Verkhnyaya Kardailovka section shows a more variable lithology, containing fewer ammonoids, abundant conodonts and ostracodes, radiolarians, and at the top of the section, foraminifers (Pazukhin et al., 2002). The Upper Serpukhovian part of the Verkhnyaya Kardailovka section contains beds of bioclastic grainstone suggesting higher energy levels compared with that in the basins further to the south. Therefore, we recognize the Verkhnyaya Kardailovka limestone as a separate facies type, different from the Dombar Limestone.

Serpukhovian beds (*Fayettevillea*–*Delepinoceras* Genozone) similar to the Dombar limestone were recorded by Stepanova (2001) on the eastern slope of the Middle Urals, on the left bank of the Iset River, in the vicinity of the town of Kamensk-Uralsk. Interestingly, micritic limestones in this section contain abundant

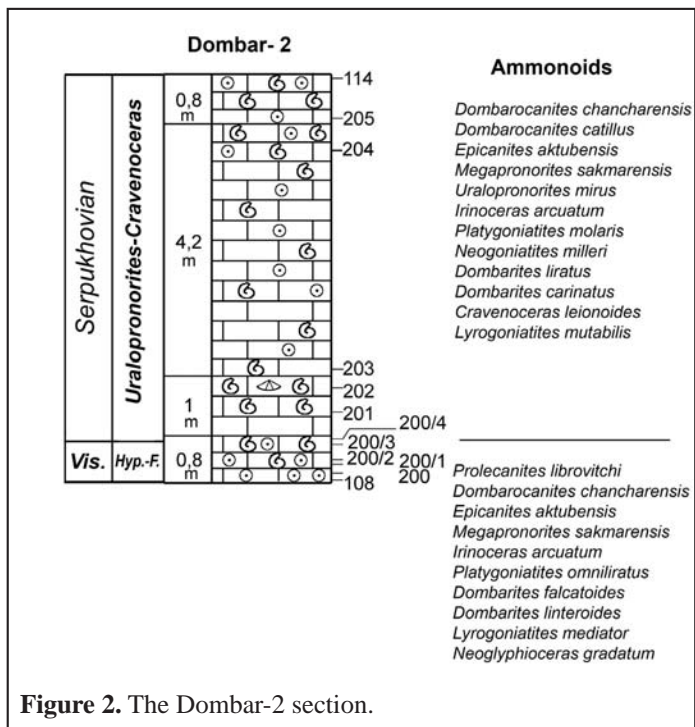


Figure 2. The Dombar-2 section.

ammonoids associated with oncolites (as in the Kyzyl-Shin Section). The Late Viséan-Serpukhovian basin in this part of the South Urals had a complex topography and a wide range of sedimentary settings, with shallow water zones inhabited by ammonoids, crinoids, and bivalves alternating with considerably deeper depressions with ammonoids, radiolarians, and conodonts and very little or no benthos. The differentiation of these two types of settings became progressively greater through the Upper Viséan into the Serpukhovian resulting in the development of highly endemic Late Serpukhovian and Bashkirian ammonoid faunas.

Acknowledgements

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Succession and correlation of the Viséan floras of the equatorial belt

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Y. V. Mosseichik recognized two distinct phases in the development of the Viséan floras of the equatorial belt that are connected with marked evolutionary changes within the major plant groups (Mosseichik, 2003; 2005a):

1. The sphenopsid *Archaeocalamites* which characterizes the Tournaisian-Early Viséan gave place to species of *Mesocalamites*.
2. Arborescent lycopsids became more abundant and phylloids became larger. The small leaf-cushion lepidophytes which dominated during the Tournaisian-Early Viséan gave place in the Late Viséan to forms with large leaf-cushions.
3. Convergent changes in frond morphology occurred among ferns, progymnosperms, and ancient gymnosperms, leading to complications of their structure, growth form, and size.
4. In the Late Viséan the quantity and diversity of lagenostomalean and trigonocarpalean seeds and male fructifications increased. In addition, the role of gymnosperms in plant communities became more significant.

This Early/Late Viséan floristic change is well expressed and permits correlation of local megafloreal zones and plant assemblages within the equatorial belt.

In the Viséan there were three continents in the equatorial belt: Euramerica (Laurussia), Kazakhstania (Kazakhstan microcontinent), and Cathasia. Their floral successions are described below.

North America. North American Viséan deposits are insufficiently characterized by plant remains (Blake et al., 1999). Therefore this region cannot be considered at this point.

Europe. Europe (European paleofloristic region: Mosseichik, 2005b) is characterized by the following floral succession: Late Tournaisian and Early Viséan floras which were dominated by the small leaf-cushion lepidophytes *Archaeosigillaria*, *Lepidodendropsis*, *Lepidodendron spetsbergense*, and *L. losseni*, the primitive sphenopsid *Archaeocalamites radiatus*, and plants with fern-like foliage such as *Adiantites* and

Triphyllopteris gave place to Late Viséan-Early Serpukhovian (Namurian A) floras with large leaf-cushion lepidophytes such as *Lepidodendron obovatum*, *L. volkmannianum*, and *Sigillaria*. The spenopsid *Mesocalamites* first appeared at this boundary and the gymnosperms and trigonocarps were actively developed. Progymnosperm, fern, and gymnosperm fronds become more diverse (e.g., first appearance of *Lyginopteris*, *Neuropteris*, and *Pecopteris*). The floras of the various regions of Europe are briefly characterized below (Fig. 1).

South Europe. France, Germany, Italy, Spain, and parts of Eastern Europe were part of the South-European paleofloristic province (Mosseichik, 2005b). The previously cited European floral succession is most completely expressed in this phytoschorion (Fig. 1). However, *Lepidodendron spetsbergense* is absent from the Early Viséan in these regions and representatives of *Mesocalamites* appear earlier.

The Early/Late Viséan floral change coincides with the boundary between the *Triphyllopteris* and *Lyginopteris bermudensisformis*–*Neuropteris antedecens* Zones in Wagner's (1984) megafloreal zonation for the equatorial belt Carboniferous. According to Patten (1957) this boundary falls near the base of the III_β goniatite zone. Wagner believed that his Carboniferous zonal succession reflected changes that were taking place throughout the entire equatorial belt. However, as he based his conclusions mainly on materials from central and southern Europe without taking into consideration the palaeophytogeographical peculiarities of the other European territories, the floral succession that he described is apparently only characteristic for the South-European province (e.g., it could not be recognized in Scotland).

Scotland. During the Early Viséan Scotland belonged to the North-European palaeofloristic province. However, due to the closure of the marine basin that previously divided North and South Europe during the Late Viséan, Scotland later became part of the South-European province (Mosseichik, 2005b). These changes of phytogeographical affinity are reflected in the Scottish floral succession (Fig. 1). The lack of *Triphyllopteris* in the Early Viséan is characteristic, as is the absence of *Lyginopteris* in the Late Viséan. The main evolutionary changes of fern-like foliage involve fronds of the *Sphenopteridium* type. Apparently in the Late Viséan migrants from South Europe such as *Neuropteris antedecens* and *Archaeopteridium tschermaki* appeared. The lycopsids are mainly represented by small leaf-cushion *Bothrodendron* which diversified in the Late Viséan. At the same time, large leaf-cushion forms such as *Lepidodendron obovatum* and *Sigillaria taylori* appeared.

In Scotland, the Early/Late Viséan floral change takes place near the boundary of the Halkierian Cementstone and Oil Shale groups (Walton et al., 1938).

Wales and Gloucestershire. In the Mississippian (Early Carboniferous) this region belonged to an island which became part of the South-European province in the Late Viséan (Mosseichik, 2005b). Its Early Viséan phytogeographical affinities are not clear. The characteristic Early Viséan genera *Adiantites* and *Triphyllopteris* are absent here although various

Rhacopteris are present. *Mesocalamites* is also not known. Peculiar endemic small leaf-cushion lepidophytes characterize the Early Viséan (Fig. 1).

In the West European miospore zonal scale the Early/Late Viséan floral changes are reflected by the boundary between the *Lycospora pusilla* and *Perotriletes tessellatus*–*Schulzospora campyloptera* Zones (Clayton et al., 1977). The Tournaisian elements *Retusotriletes incohatus*, *Auroraspora macra*, *Grandispora echinata*, *Raistrickia corynoides*, *Verrucosiporites nitidus*, *Dibolisporites distinctus*, *Speleotriletes pretiosus*, *Crassispora trychera*, *Schopfites claviger*, and *Convolvutispora circumvallata* disappear. At the same time the proportion of *Lycospora pusilla* increases, and the probable cordaitan pollen *Schulzospora* first appears.

North Europe. In North Europe similar coeval floras are known from Spitzbergen and the Moscow and Kizel coal basins (Fig. 1). A similar flora was also described from eastern Greenland. In the Viséan all these regions belonged to North-European palaeofloristic province (Mosseichik, 2005b). In the Early Viséan the province was characterized by numerous *Adiantites* species and by the absence of *Triphyllopteris*. *Mesocalamites*, *Lyginopteris*, and *Neuropteris* are unknown from these regions during the Late Viséan. The most prominent evolutionary changes occurred among lepidophytes: small leaf-cushion *Lepidodendron spetsbergense* and some other endemic species gave place to the large leaf-cushion forms *Sublepidodendron sulphureus* and *Wittbergia zaleskii*.

The most complete Viséan succession in North Europe is known from the Moscow Basin where two megafloreal zones have been established on the basis of the Early/Late Viséan floral change (Mosseichik, 2003; 2005a; plate 2). The boundary between these zones occurs within the Tulskey Horizon.

The mid-Viséan change is also reflected in the miospore assemblages of the Moscow Basin. In the middle of the Tulskey Horizon assemblages dominated by *Crassisporites*, *Euryzonotriletes*, *Knoxisporites literatus*, and *Densosporites* give place to assemblages dominated by *Granulatisporites*, *Punctatisporites*, etc. The quantity of the probable cordaitan pollen *Schulzospora campyloptera* distinctly increases (Lower Carboniferous..., 1993). These changes occur within the *Cingulizonates bialatus*–*Simozonotriletes brevispinosus* Palynozone. In the Moscow Basin the Early/Late Viséan floral change does not coincide with the boundaries of miospore zones because the last stratigraphical units were established on the basis of index-species predominance in the miospore assemblages.

Southern Russian Platform. This region includes the Donets Basin and the Lvov-Volyn' and Pripiat' depressions. In the Early Viséan the Pripiat' depression belonged to the South-European province (Mosseichik, 2005b). By the Late Viséan the Donets Basin and the Lvov-Volyn' depression were also emergent and on the territory of all three depressions the Donets paleofloristic province was established on the basis of the relic flora of the Pripiat' depression and probable migrants from Moravia (Mosseichik, 2005b). As a consequence, the complete Viséan floral succession occurs here only in the Pripiat' depression (Mosseichik, 2005a).

	South of the Russian Platform	South Europe	Wales and Gloucestershire	Scotland	North Europe
Upper Viséan	<i>Mesocalamites roeneri</i> , <i>M. haueri</i> , <i>M. ramifer</i> , <i>M. cistiformis</i> <i>Archaeocalamites radiatus</i>	<i>Mesocalamites roeneri</i> , <i>M. ramifer</i> <i>Archaeocalamites radiatus</i>	<i>Archaeocalamites radiatus</i>	<i>Calamites approximatifomis</i> , <i>Mesocalamites roeneri</i> , <i>Archaeocalamites radiatus</i>	<i>Archaeocalamites radiatus</i>
	<i>Lepidodendron obovatum</i>	<i>Lepidodendron obovatum</i> , <i>L. acuminatum</i> , <i>L. lossenii</i> , <i>Sigillaria eugenii</i> , <i>Sublepidodendron robertii</i>		<i>Lepidodendron obovatum</i> , <i>L. spetsbergense</i> , <i>Sigillaria taylori</i> <i>Bothrodendron wilkianum</i> , <i>B. depereti</i> , <i>B. kidstoni</i> , <i>B. wardiense</i>	<i>Sublepidophloios sulphureus</i> , <i>Wittbergia zaleskii</i>
	<i>Lyginopteris bermudensisformis</i> , <i>L. stangeri</i> , <i>L. falkenhainii</i> , <i>L. fragilis</i> , <i>L. bamleri</i> , <i>Neuropteris antedecens</i> , <i>N. schlehanii</i> , <i>N. bulupalganensis</i> , <i>Archaeopteridium tschermaki</i> , <i>Adiantites tenuifolius</i> , <i>Triphyllopteris rombifolius</i>	<i>Lyginopteris bermudensisformis</i> , <i>Neuropteris antedecens</i> , <i>N. antiqua</i> , <i>N. opatovicensis</i> , <i>N. gothanii</i> , <i>N. loshii</i> <i>Archaeopteridium tschermaki</i> <i>Sphenopteridium desfoursii</i> , <i>S. silesiacum</i> , <i>S. transversale</i> , <i>S. pachyrrhachis</i> , <i>S. crassum</i> , <i>S. dissectum</i> , <i>S. speciosum</i> , <i>Adiantites tenuifolius</i> , <i>A. bellidulus</i> , <i>Triphyllopteris collombiana</i> , <i>Pecopteris aspera</i>	<i>Lyginopteris bermudensisformis</i> , <i>Neuropteris antedecens</i> , <i>Archaeopteridium tschermaki</i> , <i>Sphenopteridium capillare</i> , <i>S. pachyrrhachis</i>	<i>Neuropteris antedecens</i> , <i>Archaeopteridium tschermaki</i> , <i>Sphenopteridium macconochiei</i> , <i>S. capillare</i> , <i>S. pachyrrhachis</i> , <i>S. crassum</i> , <i>S. dissectum</i> , <i>S. speciosum</i> , <i>Adiantites tenuifolius</i>	<i>Sphenopteridium</i> sp., <i>Adiantites</i> sp.
	<i>Archaeocalamites radiatus</i>	<i>Mesocalamites</i> sp., <i>Archaeocalamites radiatus</i>	<i>Archaeocalamites radiatus</i>	<i>Archaeocalamites radiatus</i>	<i>Archaeocalamites radiatus</i>
	<i>Lepidodendron spetsbergense</i> , <i>L. acuminatum</i> , <i>L. heeri</i>	<i>Lepidodendron lossenii</i> , <i>Sublepidodendron</i> sp., <i>Cyclostigma zafrensis</i>	<i>Archaeosigillaria stobbsi</i> <i>Lepidodendropsis</i> (?) <i>jonesi</i> , <i>L. recurvifolia</i> , <i>Lepidodendron</i> (?) <i>perforatum</i> , <i>Clwydia decussata</i>	<i>Bothrodendron wilkianum</i>	<i>Lepidodendron spetsbergense</i> , <i>L. acuminatum</i> , <i>L. heeri</i> <i>Gryzlovia meyenii</i> , <i>Sublepidodendron robertii</i> <i>Archaeosigillaria vanuxemii</i>
Lower Viséan	<i>Adiantites antiquus</i> , <i>A. machanekii</i> <i>Sphenopteridium flexibile</i> , <i>S. bifidum</i>	<i>Adiantites</i> sp., <i>Sphenopteridium dissectum</i> , <i>S. noeldekei</i> , <i>S. schimperii</i> , <i>S. densifolium</i> , <i>S. nobile</i> , <i>S. ginkgooides</i> , <i>S. silesiacum</i> , <i>Triphyllopteris collombiana</i> , <i>T. gothanii</i> , <i>T. rhombifolius</i> , <i>Neuropteris broilii</i> , <i>N. antedecens</i>		<i>Adiantites antiquus</i> <i>Sphenopteridium pachyrrachis</i> , <i>S. crassum</i>	<i>Adiantites geinitzii</i> , <i>A. longifolius</i> , <i>A. bellidulus</i> , <i>A. bredyana</i> <i>Sphenopteridium flexibile</i> , <i>S. bifidum</i> , <i>S. kidstonii</i>

Figure 1. Stratigraphic and geographic distribution of several characteristic Viséan plants from Europe

In the Early Viséan *Triphyllopteris* is absent in the southern Russian Platform; the Late Viséan is marked by an intensive evolutionary radiation of *Mesocalamites*, *Lyginopteris*, and *Neuropteris* (Fig. 1).

Kazakhstan. A peculiar paleofloristic realm existed on the Kazakhstan microcontinent at the beginning of the Carboniferous. During the Late Mississippian Kazakhstan “collided” with Angaraland and elements of the temperate Angaran flora appeared in eastern Kazakhstan (Vakhrameev et al., 1978). Nevertheless, elsewhere in Kazakhstan the succession of megafloral assemblages exhibits continuity with the tropical flora of the beginning of the Carboniferous (Litvinovitch et al., 1996). At the boundary between the Yagovkinsky and Dalnensky horizons a floral change which is similar to that described for the Viséan of Europe takes place (Fig. 2). *Mesocalamites*, various fern-like foliage including *Neurocardiopteris*, *Cardioneura*, and *Sphenopteris* and the trigonocarpalean plants *Aulacotheca* and *Trigonocarpus* appear at this level.

China. The Mississippian (Early Carboniferous) floras of Cathasia, which probably belonged to the peculiar palaeofloristic realm, are best known from South China.

The *Sublepidodendron mirabile*–*Adiantites* and *Cardiopteridium spetsbergense*–*Triphyllopteris collombiana* megafloral assemblages were established here (Yang et al., 1983; plate 2). The boundary between these assemblages probably occurs near the base of the Datangian Stage which is correlated with the Viséan and Early Namurian.

In the second assemblage lepidophytes with large condensed leaf-cushions such as *Lepidodendron shanyangense* and *L. volkmannianum* appear. The first representatives of the endemic gymnosperm family Parispermaceae (*Paripteris gigantea*) also appear at this level and later rapidly spread throughout China (Laveine et al., 1993). According to some data the first *Mesocalamites* also appear at this level (Zhao, Wu, 1985). *Triphyllopteris collombiana* fronds which occur in the Early Viséan in South Europe also appear here and become a characteristic species only in analogues of the upper part of Viséan.

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Pennsylvanian fern taxonomy: New approach through the compact model

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Introduction

As a general statement, the compact model (Pšenička, 2005) refers to the methodological approach through which a more natural fossil plant taxonomy is possible for comparison with certain living fern groups, marattialean and filicalean ferns (see von Sternberg in 1820: *Versuch*; and Brongniart in 1828: *Histoire des Végétaux Fossiles*). Recently, Sakala (2004) described the whole-plant concept for Tertiary plants, and successfully used it for comparison with certain living plants. In this context, the emphasis of the investigation centers on paleobiological and related data. At the same time, the model provides a general blueprint for similar treatment of other floral groups of the upper Paleozoic for which a more natural taxonomy is sought (i.e., replacing the traditional taxonomic designations of morphospecies and morphogenus). However, the concept and designation of morphospecies is not abandoned or negated in this model, which recognizes the reality of preservational processes (taphonomy, diagenesis, geochemistry). Ultimately these factors dictate the level to which useable paleobotanical information can be reliably extracted from the macrofloras, and thereby setting the methodological course for an investigation (i.e., compact or the morphogeneric model).

Data Base

The data base (n=1,200 pectopteroid specimens with a fair representation of fertile material) is the the largest ever assembled in the history of the study of pectopterids of Bolsovian–Asselian age. Of these, 700 originated from the basal Cantabrian of the Sydney Coalfield (Zodrow et al., 2000), 450 are from various coal basins in the Czech Republic, 45 are from France, and 5 are from Austria. From these, 109 larger and well-preserved, coalified specimens were critically selected for exhaustive investigation. It is important to emphasize that cuticles were recovered from 62% of the specimens, and that sporangia and *in situ* spores, including sporangial mother-spore tissue, were recovered from more than 70% of the fertile specimens.

The Compact Model

Various interpretations have been suggested relative to the taxonomy of pectopterid groups. The main problem centers around how to separate pectopterid species. For example, Wagner (1958a, 1958b) preferred morphological characters of pinnae and pinnules, together with venation pattern. This is clearly an example of the “geological” view or model for separating pectopterids and can be criticized because data relating to *in situ* reproductive organs as taxonomic parameters are omitted. The term “geological” view refers to the description of morphological features such as the shape of the pinnules or the type of venation which is used for quickly determining [form] species, but beyond

that it can lead to the separation of natural species into two or more artificial species. Admittedly, pectopterid fronds were large and morphological characters variable between the basal and upper parts of a frond. This can lead increasingly to confusion in this group as far as species separation is concerned. A second view or model is that which attempts to adopt a more natural classification of pectopterid species, as distinguished from form classification. This view takes into account types of reproductive organs together with spores, and was practiced to a degree by Corsin (1951), Laveine (1969, 1970), and others. This view is emphatically advocated and used in this work, which also, however, incorporates data from cuticular analysis as an integral part for systematically separating pectopterid species. This is termed the compact model. Four (1 to 4) input-data categories define the workings of this model.

(1) **Foliar morphology.** This follows the blueprint established by the pioneering fern taxonomists of nearly 200 years ago (e.g., Presl) and great fern morphologists (e.g., Goebel, Bower, and von Ettingshausen) who used lateral-vein characteristics for species- and even family-level categories (see Wagner, 1979 for summary). In effect, this approach has stood the test of time, as it is still part of fern classification utilized by modern pteridologists.

(2) **Reproductive organs.** Sporangia were carefully detached from the compressed pinnules, mounted, and examined under SEM and light microscopes for structural detail. Then a partial or entire sporangium was quickly macerated for a few minutes to obtain spores. The alkaline potassium chlorate treatment was generally omitted. In many cases this assured recovery of entire *in situ* spore masses (e.g., Zodrow et al., 2005a, pl. 8, fig. 1) suitable for determining ontogenetic stages of spore growths.

(3) **Cuticles.** Extraction of fern cuticles suitable for mounting and study, however, required patience and careful chemical manipulation, as fossil-fern cuticles are notoriously thin, delicate and not highly cutinized, as originally noted by Barthel (1962). Attention was paid to typifying the stomatal apparatuses, and to precise description of topographies, co-ordinating terminology with that of living ferns (Sen and De, 1992).

(4) **Anatomical characteristics.** Although not consistently preserved in compressions, data on anatomical details such as tracheidal and xylemic structures in ultimate and penultimate rachides are organized in what is termed a “similarity data matrix” for interpretive studies. Highly ranked in this approach, and an integral part of the compact model, are critical comparisons with types and comparisons among types themselves.

Results

The “similarity data matrix” with 27 species and 9 genera of ferns was used to distinguish two main fern groups on the basis of leptosporangiate and eusporangiate characteristics. Nevertheless, some genera can be related to an intermediate group, the so-called proleptosporangiate ferns. This includes species of *Corynepteris* Baily, *Senftenbergia* Corda, *Oligocarpia* Goeppert, *Sonapteris* Pšenička et al., *Discopteris* Stur, *Zeilleria* Kidston, *Pecopteris* Brongniart, and *Acitheca* Schimper. The main effort, however, is directed toward interpreting the eusporangiate pectopterid data

through the four proposed groups (1 to 4).

(1) *P. miltonii*: *P. aspidioides*, *P. polypodioides*, *P. micromiltonii*, *P. alpina*, and *P. miltonii*.

(2) *P. arborescens*: *P. cyathea*, *P. hemitelioides*, *P. nyransensis*, *P. tuffitica*, sp. nov. and *P. arborescens*.

(3) *Acithea polymorpha*: *A. ambigua*, *A. alii*, and *A. polymorpha*.

(4) *P. unita*: *P. campbelli* and *P. unita*.

Remarks: One outstanding problem is that the *in situ*-spore comparison is through the “strait-jacket” of *sporae dispersae*: i.e., a natural system of palynology remains a future development (Thomas and Taylor, 1993). In the comparison, only types were used and not interpretations offered by other authors. A variety of groupings of course is possible by assigning different “taxonomic weights” to the (1) to (4) data categories. For example, if the stomatal type is assigned primary taxonomic weight, two groups (I) and (II) instead of (1) to (4) are evident, (i.e., Group I cyclocytic or anomocytic type: *P. aspidioides*, *P. polypodioides*, *P. micromiltonii*, *P. miltonii*, *P. arborescens*, *P. cyathea*, and *Acithea polymorpha*; and Group II paracytic type: *P. nyransensis*, and *P. unita*). Therefore, the groups (1) to (4) are necessarily regarded as provisional; they nevertheless represent the first substantive revision since Corsin (1951) towards a natural classification system.

Additional Remarks

The detailed results of this investigation permit the general observation that leptosporangiate ferns, as representative of some modern forms, were widespread in Pennsylvanian time, but in contrast with eusporangiate ferns (marattialean) produced relatively fewer numbers of spores. This realization likely contributes to the current view of their [observed] provincial nature, which, in effect, does not correspond with actual biogeography. We share Bierhorst’s (1971) second thoughts, and not Bower’s (1963, II) view necessarily, that the leptosporangiate ferns are the oldest phylogenetic forerunners of extant ferns. However, leptosporangiate ferns, such as *Senftenbergia plumosa*, co-occur with marattialean in Canada, the Czech Republic, and elsewhere. Also, stomatal types on sporangial tissue do not necessarily correspond with those of the pinnule laminae of the same specimen, in agreement with observations on relevant extant ferns by Van Cotthem (1970, 1973). Although cuticular characteristics are significant parameters for Pennsylvanian fern taxonomy, comparing fossil with extant ferns solely on that basis is not warranted.

The acquisition of this unparalleled data base of *in situ* fern palynology demonstrates that although spores are taxonomic parameters, their sole use for specific taxonomic determinations is not warranted as only comparison with dispersed spores can be made at this time (see also Zoderow et al., 2005b). The problem is certainly highlighted by the large exinuous variability of *in situ* spores of *Acithea polymorpha* which can be compared with at least three specific palynomorphs. In addition, the enormous size range (37 µm to 116 µm) encompasses nearly all known fern spores, save, for example, the small laevigate spores of *P. arborescens* (Zoderow et al., 2005a, table 2).

From a stratigraphical perspective, form alone is an insufficient parameter for mapping phylogenetic lineages through time, but a necessary “workhorse” as a first approximation for a phytostratigraphical subdivision. The compact model is an important first step in offering a more “natural” (evolutionarily) fern biostratigraphy than is possible with the biostratigraphical (geological) model. It is entirely possible that with the accumulation of more data through time, the compact model (or some form of it) will become the preferred methodological approach to a “natural” Carboniferous plant biostratigraphy.

Conclusions

This work suggests that the compact model offers the best strategy yet devised for classifying pectopterid species, but at the same time highlights the problem that the resulting taxonomy and phylogenetic reconstruction is influenced by preservational pathways with variable loss of information. The question that arises is “what is left preserved in the pectopteroid compressions/cuticles that as yet are untapped informational sources to augment the number of parameters in the compact model in continued support for a more natural taxonomy”? Two are suggested. The first, although already rudimentarily considered in the thesis, is the systematic study of epicuticular trichomes, earlier suggested by Bower (reprint 1963, I), done for some extant ferns by Blunden and Jewers, (1973), and used by Oliver and Scott (1904) as correlative tool for pteridospermous reconstruction when only fragmentary material was available. The second is the biochemical make-up that is still preserved, particularly in mesophyllous remains. Although the palaeophytochemical approach is still in its infancy, its feasibility is convincingly demonstrated by remnants of certain metabolites in the marattialean fossil fern *Pectopteris arborescens* (Jessome, 2004), and also by preserved functional carbon groups in the *P. arborescens* and *P. miltonii* groups (Pšenička et al., 2005).

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- Moscovian boundary (Groves, 2005). It has a very distinctive morphology and widespread occurrence, and has been found close to the traditional lower boundary of the Moscovian Stage in central Russia, Ukraine, several countries in Western Europe, and possibly also in Alaska and South America.

This species was not known in the main Bashkirian reference section (Askyn) in the South Urals, but its ancestor *D. marginodosus* occurs in many sections of that area. Recently *D. donetzianus* was recognized in the Basu River section (Fig. 1), along with *D. marginodosus*. The Basu River section is situated on the western slope of the South Urals in the Inzer River basin, 20 km NNE of the Askyn section, the hypostratotype of the Bashkirian Stage. Its location near a highway makes this section accessible for investigation. The lower part of the section is exposed in a roadcut, and the upper part in a quarry. The Bashkirian-Moscovian boundary beds are represented by lime mudstones and wackestones, probably of deeper-water facies than those in the Askyn section. The rocks in the studied interval contain foraminifers, brachiopods, bryozoans, conodonts, crinoids, and algae. Preliminary study of 13 samples from the lower part of the section show that *D. donetzianus* occurs in evolutionary continuity with its ancestor *D. marginodosus*. Stratigraphic ranges of some important taxa are shown in Figure 1.

The conodont assemblage at this level also contains *D. marginodosus* (Grayson), *Idiognathoides ouachitensis* (Harlton), *Id. sinuatus* Har. and Hol., *Id. tuberculatus* Nem., *Idiognathodus aljutovensis* Alekseev et al., and *Hindeodus minutus* (Ellison). The foraminiferal species are *Eostaffella kashirica* Raus., *Neostaffella* spp., *Depratina prisca* (Deprat), *D. cf. sphaeroida* (Raus.), *Schubertella gracilis* (Raus.), *Profusulinella ex gr. rhomboides* (Lee and Chen), *Asteroarchaediscus ex gr. baschkiricus* (Krest. and Theod.), and *Neoarchaediscus incertus* (Groz. and Leb.).

D. donetzianus also occurs in Vereian strata in boreholes from the Bashkirian part of the Russian Platform. The presence of this species in the South Urals is important, because it extends its geographic range to the east, and, especially significantly, to a deeper-water facies than in the Moscow and Donets Basins. This discovery will help in the search for the most correlatable marker level and ultimately the GSSP for the base of the Moscovian Stage. More detailed studies are planned on this section later this year.

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Discovery of potential Bashkirian-Moscovian boundary marker conodont *Declinognathodus donetzianus* in South Urals

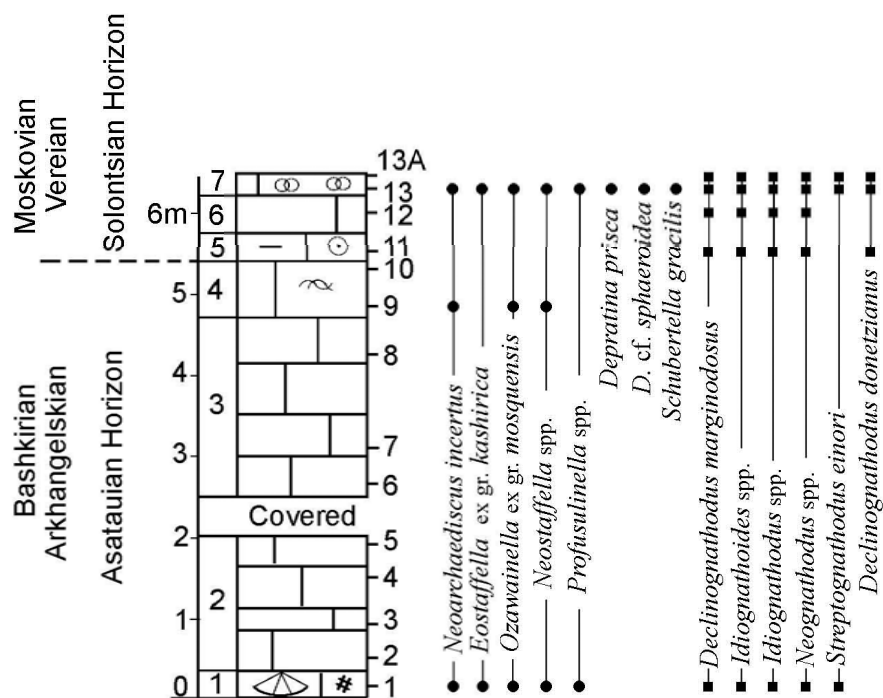
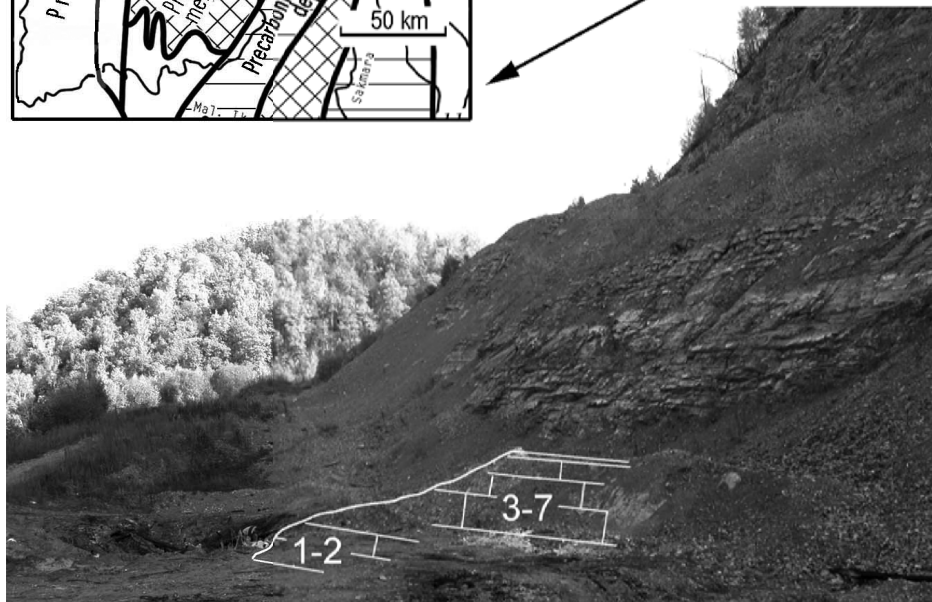
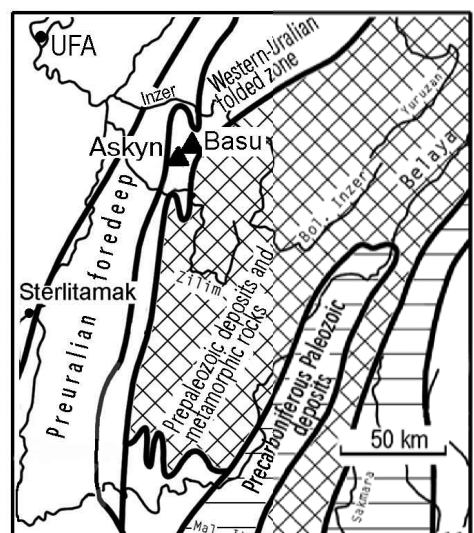
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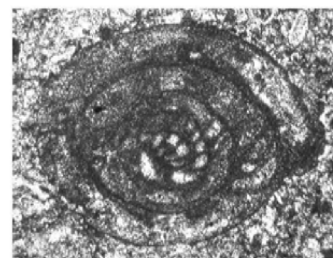
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The conodont species *Declinognathodus donetzianus* is one of the potential marker taxa that were proposed by the Task Group to establish a GSSP close to the existing Bashkirian-



D. donetzianus



D. prisca



Sch. gracilis

Figure 1. Location of Basu River section, photograph of outcrop, distribution of most important conodont and foraminiferal taxa across Bashkirian-Moscovian boundary interval, and photographs of conodont *D. donetzianus* (60X) and foraminifers *Depratina prisca* and *Schubertella gracilis* (scale in mm).

Fusulinoida of the Kasimovian-Gzhelian transition in the northern Timan

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The Timan Ridge is characterized by the widespread development of Upper Paleozoic carbonates which range in age from Serpukhovian (Mississippian) to Artinskian (Lower Permian). In paleogeographic terms the northern Timan is situated near the juncture of the Arctic and East-European provinces. Thus paleontological data on this region are very important for correlation.

In this report we analyze Upper Kasimovian–Lower Gzhelian fusulinid assemblages from the Malaya Pokayama (Fig. 1) and Bolshaya Pokayama (Fig. 2) sections which are located in the Volonga River basin.

Late Kasimovian Fusulinoida

The highest Kasimovian *Rauserites quasiaercticus*–*Triticites acutus* fusulinid Zone is recognized in both of the studied sections based on the presence of the index species *R. quasiaercticus*. The second zonal species, *T. acutus*, is absent. However, *T. aff. subacutus* Mikhailova occurs in the Malaya Pokayama section. Species of *Quasifusulina* and *Rugosofusulina* dominate this assemblage. Numerous primitive *Rugosofusulina* ex gr. *prisca* (*R. ovoidea* Bensch, *R. exiqua* Remizova, *R. pleiomorpha* Remizova) characterize the base of this zone. They are associated with weakly folded *Triticites* (*T. explanatus* Remizova, *T. simplex* Schellwien, *T. incomptus* Remizova and others). Additionally interesting is the presence of the original *Triticites* (?) with subsphaerical shells (*T. globoides* Z. Mikhailova and *T. tumefactus* Remizova). Species of *Rauserites*, including *R. quasiaercticus* Solovieva, *R. paraercticus* Rauser, and *R. vetustus* (Schellwien), are also common, especially in the uppermost part of this zone in the Bolshaya Pokayama section.

Early Gzhelian Fusulinoida

The Lower Gzhelian in the northern Timan is characterized by the undifferentiated *Rauserites rossicus*–*R. stuckenbergi* and *Jigulites jigulensis* fusulinid Zones. In both sections the Gzhelian is recognized on the basis of the appearance of an assemblage composed of advanced *Rauserites*. In addition to the index species *R. rossicus* and *R. stuckenbergi*, there are a few species typical of the Russian Platform, such as *R. pseudoarcticus* Rauser, and many endemic species, such as *R. schellwieni* Grozdilova, *R. parairregularis* Grozdilova, and *R. nefandus* Grozdilova, among others. *Jigulites* is rare in this assemblage and does not permit the recognition of a separate, discrete *Jigulites jigulensis* Zone. The upper limit of this interval is marked by the appearance of an abundant *Daixina* assemblage.

Correlation

Upper Kasimovian

The Upper Kasimovian strata of northern Timan belong to the *Rauserites quasiaercticus*–*Triticites acutus* fusulinid Zone. The fusulinid assemblage of this zone is more diverse here than in the stratotype area in the Moscow Basin, but it can be correlated with Dorogomilovian Horizon based on the presence of the index species *Rauserites quasiaercticus*. The Timanian assemblages most closely resemble assemblages described from the Chernyshev Ridge and the North Urals (Mikhailova, 1967). Many of the same species of *Rauserites* and *Triticites* occur in both regions, including *T. petschoricus*, *T. subacutus*, *T. globoides*, and *R. tenebrosus*. *T. subacutus* is widely distributed throughout the Urals and the Timan-Pechora Basin. In addition, this species is very close to the Asiego (Northern Spain) forms, as noted by E. Villa and A. C. Ginkel (1999). Thus, *T. subacutus* may be considered as a zonal species for the Upper Kasimovian.

The next characteristic assemblage of primitive *Rugosofusulina* is very significant for correlation of Upper Kasimovian strata, especially in the Arctic Province. This Timanian assemblage is similar to the *Rugosofusulina flexuosa* Zone assemblage described from north Greenland (Davydov et al., 2001). Davydov et al. considered this zone to be of Early Gzhelian age. However, they noted poorly preserved specimens of *Rauserites* from the *Rugosofusulina flexuosa* Zone. As for *Rugosofusulina*, the first appearance of this genus is dated as Late Kasimovian in many regions (northern Timan, Timan-Pechora Basin, Urals, Precaspian, and Central Asia). Moreover, the nominate species, *Rugosofusulina flexuosa*, was described by S. E. Rosovskaya (1958) from Carboniferous strata C3B (i.e., Upper Kasimovian). Based on the nearly identical specific compositions of *Rugosofusulina* assemblages in northern Timan and north Greenland, we consider their correlation to be established. Since the age of the Timanian assemblage has been determined to be Late Kasimovian based on associated species of *Triticites* and *Rauserites*, we suggest the age of the *Rugosofusulina flexuosa* Zone in north Greenland is also Late Kasimovian.

Lower Gzhelian

The Gzhelian strata of northern Timan are defined by the first appearance of the zonal species *Rauserites rossicus* (Schellwien). Here there is an abundance of mostly endemic *Rauserites* species. A similar fusulinid assemblage is known from the Gzhelian of the Kanin Peninsula. The specific feature of the Gzhelian strata of Timan is their two-fold subdivision based on Fusulinoida. The lower two zones of the standard scale (*Rauserites rossicus*–*R. stuckenbergi* and *Jigulites jigulensis* Zones) are represented by a single undifferentiated fusulinid assemblage. The overlying *Daixina sokensis* Zone is traceable along the entire Timan Ridge. The same situation is characteristic for the Timan-Pechora Basin and the North Urals.

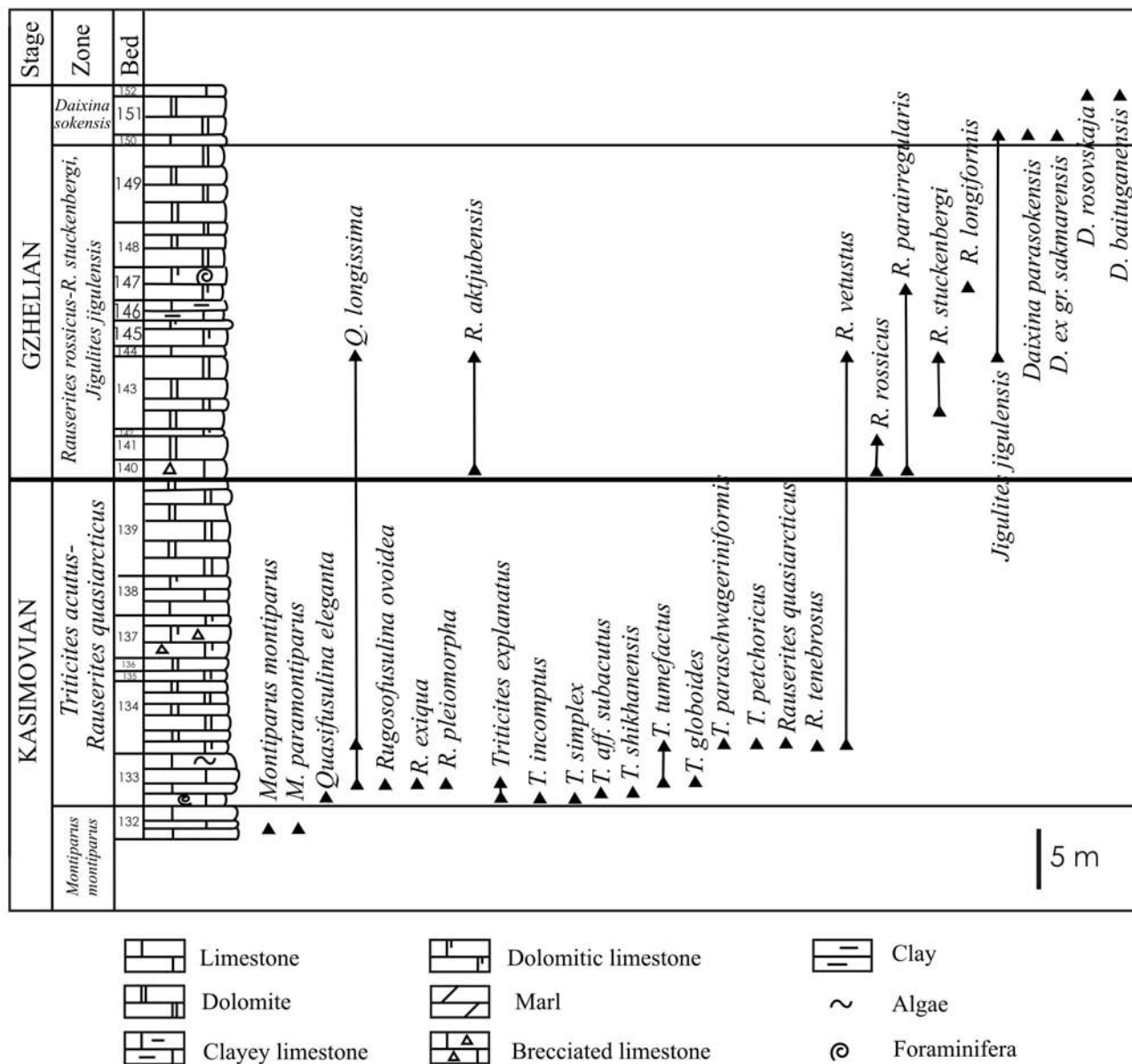
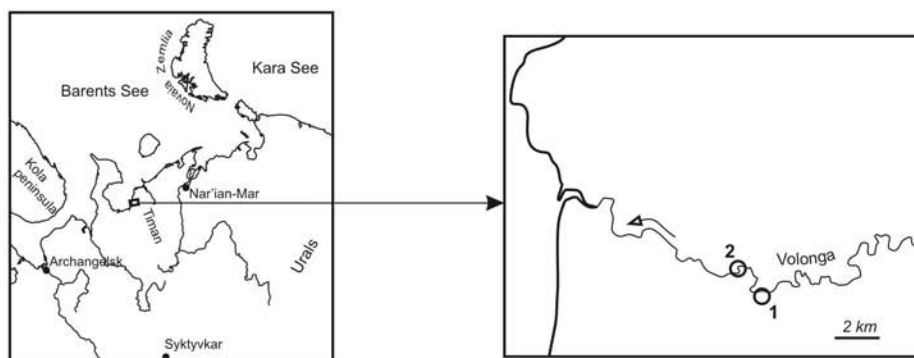


Figure 1. Location of the Malaya Pokayama (1) and Bolshaya Pokayama (2) sections in the northern Timan; and stratigraphic section showing distribution of important fusulinid taxa across the Kasimovian-Gzhelian boundary in the Malaya Pokayama section.

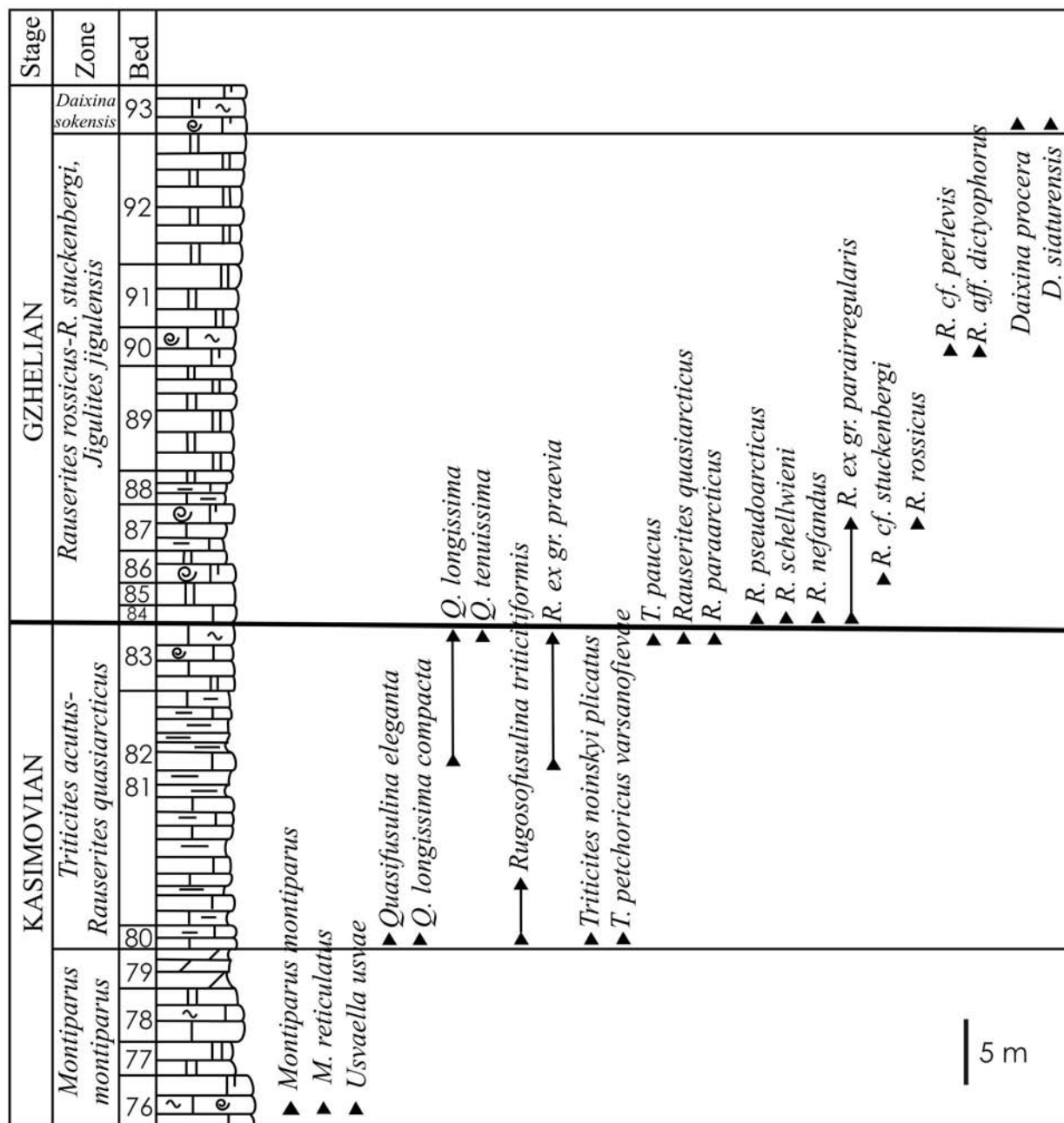


Figure 2. Stratigraphic section showing distribution of important fusulinid taxa across the Kasimovian-Gzhelian boundary in the Bolshaya Pokayama section.

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Potential candidate for GSSP to define base of Gzhelian Stage in global chronostratigraphic scale: Usolka section, southern Urals, Russia

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Introduction

In the recent report of the Task Group to establish a GSSP at the Kasimovian-Gzhelian boundary (Villa and Task Group, 2005) and in a series of recent publications (Heckel et al., 2005; Chernykh, 2005; Menning et al., in press; etc.), the conodont species *Streptognathodus simulator* Ellison 1941 (regarded as *Idiognathodus* by some authors) has been proposed as the best index-fossil for the definition of the base of the global Gzhelian Stage. This species was originally described from the Heebner Shale Member of the Oread Limestone (Ellison, 1941) in Midcontinent North America, and has been traditionally used as a marker for the boundary in the Moscow Basin (Barskov and Alekseev, 1979) and in the Urals (Chernykh and Reshetkova, 1987; Davydov and Popov, 1991; Chernykh, 2002). Therefore it easily can be adopted in the stratotype region as the event marker for the base of the global Gzhelian Stage. Heckel et al. (2005) have shown that this species is definitely global in distribution. Moreover, the taxonomy of the species has been updated recently by Barrick et al. (2004), who recognize two separate species: *St. simulator* [sensu stricto], the concept of which is based on the holotype from Midcontinent Heebner Shale of the Oread cyclothem, and its potential ancestor *St. aff. simulator*, which occurs in the older Midcontinent Eudora Shale of the Stanton cyclothem and the Merriman-Upper Winchell cyclothem of Texas (Heckel et al., 2005). Current studies of upper Paleozoic stratigraphy and biostratigraphy in the Urals during the last few years (Chuvashov et al., 1990, 1993, 2002, Davydov and Popov, 1986; Leven and Davydov, 2001; Davydov and Leven, 2003) have established a refined biostratigraphic framework for this time interval and described several new conodont species (Chernykh, 2002, 2005). The latter publication establishes a chronocline of *Streptognathodus praenuntius* Chernykh, 2005 – *St. simulator* Ellison – *St. auritus* Chernykh, 2005, which is recovered within 2.7 m of beds 4 and 5 at the Usolka section, with all three species described and properly figured. We propose here the Usolka section as a potential candidate for establishing a GSSP for the base of the global Gzhelian Stage.

Material

The Usolka section is located approximately 120 km southeast of Ufa and about 60 km northeast of Sterlitamak on the northeastern margin of the city of Krasnousolsk, just north of the Usolka River across from the hot-springs resort, in the

Bashkortostan Republic of Russia (Fig. 1). This section is exposed along the roadcut on the right bank of the Usolka River in the core of the meridionally striking Usolkian brachianticline. The section occurs in the axial part of the Belsk depression in the relatively deeper-water portion of the Preuralian Foredeep, and therefore the sedimentary succession there is likely to be relatively undisturbed.

The section starts with dolomitic limestone with chert nodules and rare volcanic ash beds of the Zilim Formation, approximately 10-12 m thick, which is overlain across a covered interval by the predominantly mixed carbonate-siliciclastic succession of the Kurkin (or Kurortnaya) Formation (Fig. 2). During a 2001 field trip, we collected samples and recovered conodonts at the top of the Zilim Formation. Conodonts there include typical Moscovian *Neognathodus* and are under current study. The measured thickness between the exposed top of the Zilim Formation and bed 1 of the Kurkin Formation in the section is approximately 5-6 meters (beds 1, 2 and part of 3 are currently covered).

The Kurkin Formation contains numerous micritic limestone beds and up to 50 volcanic ash layers (Fig. 2) more or less evenly distributed throughout the section (Davydov et al., 2002, 2003). More general information and details on the section can be obtained from several sources (Chuvashov et al., 1991; 1993; Chuvashov and Chernykh, 2002). Chernykh (2005) provided the most comprehensive record of conodont distribution in the section. Because of the undisturbed sedimentary record and abundance of conodonts in the section, higher parts of the Usolka section were proposed as an auxiliary section for the Carboniferous-Permian boundary (Chuvashov et al., 2002), and as a candidate for the GSSP for the base of the Sakmarian Stage (Wardlaw et al., 1999).

The lithology of the Kasimovian-Gzhelian transition is not yet described in detail, but we plan to re-measure and describe it during the summer 2006. Our plan is to collect additional conodont samples at a centimeter scale along with samples for fusulinids, smaller foraminifers, and volcanic ash beds where the lithology is appropriate. Below is the latest available description of the Kasimovian-Gzhelian transition (Chuvashov and Chernykh, 2002), in ascending order of numbered beds (with thicknesses based on Fig. 2; beds 1-3 are currently mostly covered)

1. Thin-bedded, slightly silicified dark-grey to black siltstone with bioclastic debris in the uppermost part. Acritarch and mispores are found in siltstone 1.1 m
2. Bluish-grey microgranular to micritic limestone, strongly silicified in the lower 10-12 centimeters. One orange-yellow volcanic ash layer has been found in this bed. In the middle of the bed, a lens of packstone to grainstone limestone contains smaller foraminifers, rugose corals, brachiopods, crinoids, and conodonts *Idiognathodus delicatus* Gunnell, *Id. sagittalis* Kozitskaya, *Id. tersus* Ellison, *Streptognathodus cancellosus* (Gunnell), *Gondolella sinuata* Gunnell, *G. merrilli* Gunnell..... 0.4 m
3. Bluish-grey, strongly silicified, medium to thin-bedded (5-20 cm), slightly silty micritic limestone interbedded with grayish foliated, silicified siltstone. Two very thin (2-3 cm)

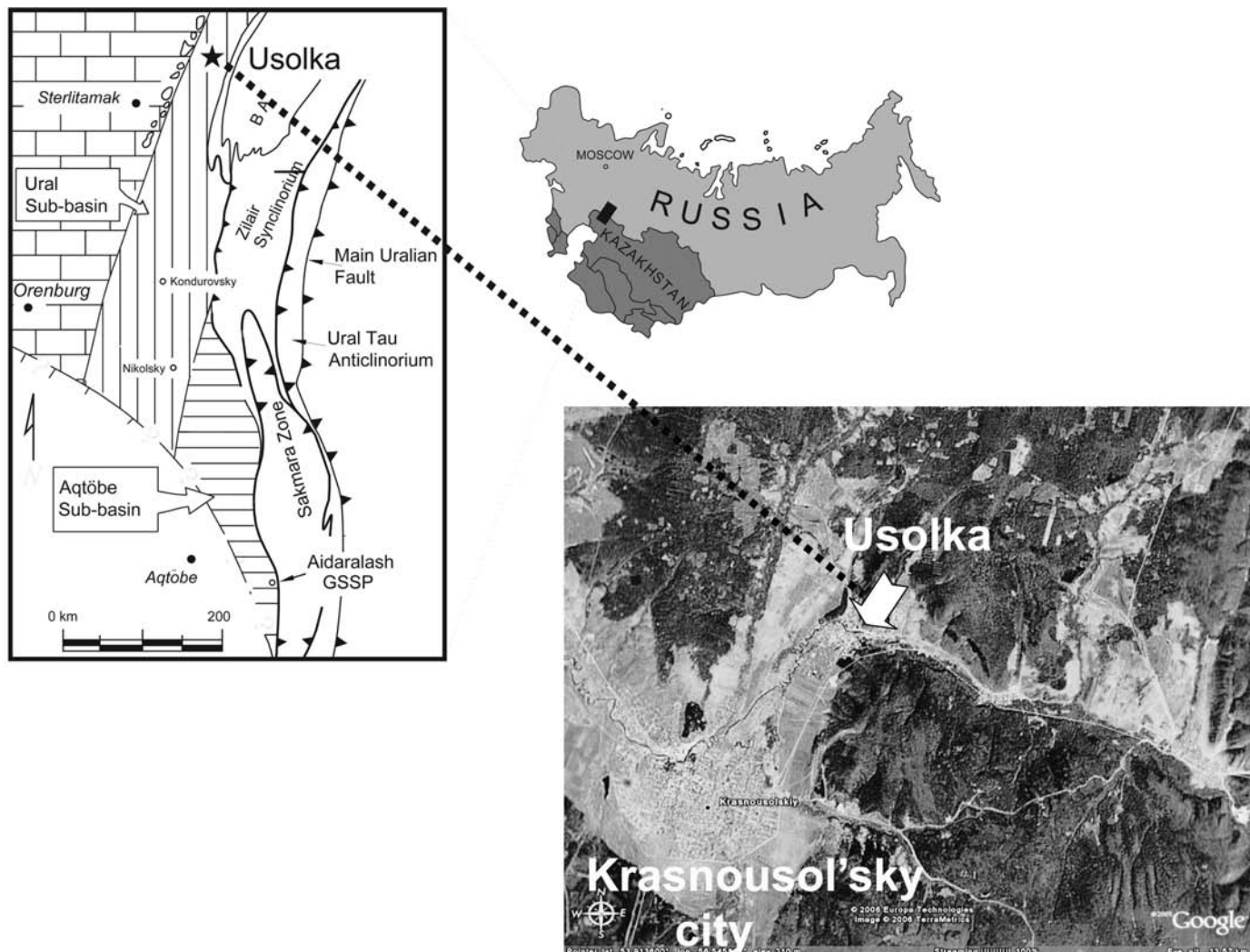


Figure 1. Location map and Google Earth image of Usolka section, southern Urals, Bashkortostan, Russia.

orange-yellow volcanic ash layers occur within the lower third of this bed. In the uppermost part of the bed, a few very thin (1-2 cm) layers of packstone to micritic limestone occur. Packstone contains smaller foraminifers, brachiopods, crinoids, and other bioclastic debris. Radiolaria and sponge spicules are found in the micritic layers. Conodonts *Idiognathodus delicatus* Gunnell, and *Id. tersus* Ellison are found in this bed... 4.0 m

4. Alternations of dolomitic micrite and siltstones. Dolomite layers are 0.18-0.3 m thick, dark-grey, microgranular, and contain smaller foraminifers, brachiopods, crinoids and conodonts. At the top of bed 4 is a relatively thick (0.7 m) layer of grayish packstone with small lenses of fine grainstone at its base (bed 4-1), where smaller foraminifers, fusulinids, brachiopods, and rugose corals are found. The following species are identified among fusulinids: *Quasifusulina* ex gr. *longissima* (Moeller), *Pseudofusulinella minuta* (Grozdilova), *Ps. pulchra* (Rauser and Belyaev), *Schwageriniformis petchoricus brevis* (Rauser and Belyaev), *Sch. petchoricus varsanofievi* (Z. Mikhailova), *Sch. schwageriniformis mosquensis* (Rosovskaya), *Schwageriniformis baisunensis* (Bensh),

Schwageriniformis (Tumefactus) sp., *Rauserites bashkiricus* (Rosovskaya), *R. shikhanensis compactus* (Rosovskaya), *Rauserites dictiophorus* (Rosovskaya). Conodonts in the lower part of this 0.7 m limestone layer are: *Streptognathodus firmus* Kozitskaya, *St. gracilis* Stauffer and Plummer, *St. zethus* Chernykh and Reshetkova, *St. pawhuskaensis* Harris and Hollingsworth, *St. praenuntius* Chernykh 2005, *Gondolella* ex gr. *merrilli* Gunnell, and some other conodonts that are undergoing study. 20 centimeters above, in bed 4-2 (Fig. 2), the assemblage of conodonts is more diverse and includes: *Streptognathodus elegantulus* (Stauffer and Plummer), *St. firmus* Kozitskaya 1978, *St. gracilis* Stauffer and Plummer, *St. makhlinae* Alekseev and Goreva, *St. simulator* Ellison, *St. dolioliformis* Chernykh 2005, *St. pictus* Chernykh 2005, and *Id. undatus* Chernykh 2005... 1.1 m

5. Predominantly micritic limestone in layers 0.05 to 0.2 m thick, with a few thin (0.1-0.2 m) siltstone layers. Micritic limestone contains conodonts *Idiognathodus lobulatus* Kozitskaya, *Id. brevisulcatus* Chernykh 2005, *Id. pictus* Chernykh 2005, *Streptognathodus luganicus* Kozitskaya, *St. pawhuskaensis* (Harris and Hollingsworth), *St. simulator* Ellison, *St. auritus*

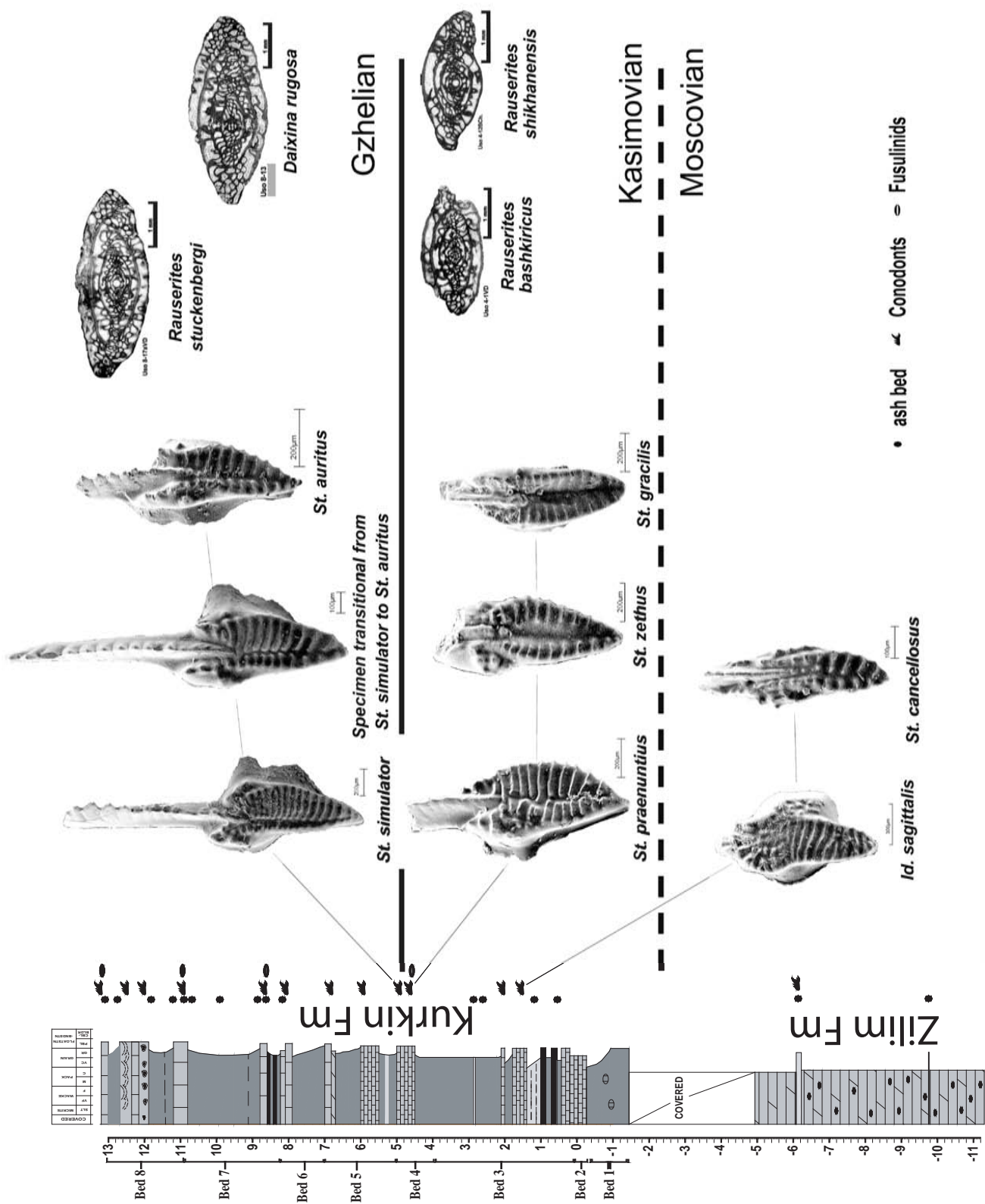


Figure 2. Distribution of conodonts and fusulinids within Kasimovian-Gzhelian transition in Usolka section. Bed boundaries are shown by tick marks across from bed numbers on line to left of metric scale.

- Chernykh 2005, and *Gondolella sub lanceolata* Gunnell 2.1 m
6. Grey silicified siltstone and thin layers of micritic limestone. Three volcanic ash layers are found in the upper third of this bed 1.2 m
7. A band of silty brownish-grey, fine-grained dolomite with conchoidal cleavage (0.3 m thick) forms the bottom of this bed, overlain by brownish-grey siltstone with numerous calcareous and phosphatic small concretions (3-5 cm) and one orange-yellow 3-cm ash layer. The upper part of the bed consists of grey dolomitized limestone with one ash layer near the top. The dolomite contains smaller foraminifers, poorly preserved fusulinids, brachiopods, crinoids, and conodonts. The latter are *Streptognathodus auritus* Chernykh, 2005, *St. elegantulus* (Stauffer and Plummer), *St. luganicus* Kozitskaya, *St. pawhuskaensis* (Harris and Hollingsworth), *St. simulator* Ellison, *Idiognathodus pictus* Chernykh, 2005, and *Id. sagittalis* Kozitskaya. The following species are found among the fusulinids: *Pseudofusulinella eopulchra* (Rauser), *Ps. usvae* (Dutkevich), *Quasifusulina cf. elegantula* Schlykova, *Rauserites dictiophorus* (Rosovskaya), *R. shikhanensis* (Rosovskaya), *R. cf. cybea* (Putrja)..... 2.6 m
8. Alternation of dolomitic marl and grey foliated siltstone. A lens of graded grainstone occurs 10 cm above the base of the bed. Five volcanic ash layers are recognized within bed 8. The lower part of the grainstone contains fish remains, brachiopods, and diverse fusulinid and conodont assemblages. Conodonts: *Idiognathodus lobulatus* Kozitskaya, *Id. tersus* Ellison, *Streptognathodus simulator* Ellison, *St. eccentricus* Ellison, *St. pawhuskaensis* (Harris and Hollingsworth), *St. elegantulus* (Stauffer and Plummer), *St. insignitus* Akhmetshina. Fusulinids: *Quasifusulina eleganta* Schlykova, *Rauserites stuckenbergi* (Rauser), *R. petchoricus* (Rauser and Belyaev), *R. triangulus* (Rosovskaya), *R. elongatissimus* (Rosovskaya), *R. mogutovenski* Rosovskaya, *R. noinskyi* (Rauser), *R. tjanshanensis* (Bensh), *R. samaricus* (Rauser), *R. sphaericus* Rosovskaya, *R. variabilis* (Rosovskaya), *Schwageriniformis kurshabensis* (Bensh), *Sch. perstabilis* (Scherbovich), *Sch. baisunensis* (Bensh), *Sch. fusiformis* (Bensh), *Daixina rugosa* Rosovskaya 2.2 m.

Analysis

In the described succession (Fig. 2), bed 1 was not sampled for either conodonts or foraminifers. It is currently not exposed, and therefore its age cannot be determined. However, because conodonts recovered 6 meters below the top of the Zilim Formation are Moscovian *Neognathodus*, bed 1 is in a transitional position between the Moscovian and Kasimovian Stages. Beds 2 and 3 have yielded the typical Kasimovian conodonts *Id. sagittalis* Kozitskaya and *Streptognathodus cancellosus* (Gunnell), and thus belong to the Kasimovian Stage. Bed 3 was not properly sampled in the past, so we will re-sample it in greater detail. In the lower part of bed 4 (4-1) at 4.7 meters above the base of the section (mab), the conodont assemblage is more advanced than in bed 3, with the species *St. zethus* Chernykh and Reshetkova and *St. pawhuskaensis* Harris and Hollingsworth, of which the former marks the base of the

regional Virgilian Stage in North America (Heckel, 2004). The newly described species *St. praenuntius* Chernykh 2005, which closely resembles *St. simulator*, also occurs in this level (Fig. 2). The fusulinid assemblage that is found at the same level is usually characteristic of the late Kasimovian, although some species range up into the lower Gzhelian. In the upper part of bed 4 (4-2), starting from 4.9 mab, *St. elegantulus* and *St. simulator* occur. The latter species, as mentioned above, is the traditional index for determining the base of the Gzhelian Stage in the Moscow Basin and the Urals. Upwards, in bed 5 at 6.4 mab, the conodont assemblage is very similar to that from bed 4-2, except that new and more advanced forms that resemble *St. simulator* occur. These forms were recently described as a new species *St. auritus* Chernykh, 2005 (Figs. 2, 3). No fusulinids were found in beds 5 or 6, and the fusulinids that were recovered from bed 7 (8.2 mab) are poorly preserved. In bed 8 (10.8 mab), the typical Gzhelian species *Rauserites stuckenbergi* and *Daixina rugosa* were recovered among other fusulinid species (Fig. 2).

Discussion

The traditional base of the Gzhelian in the Moscow Basin was proposed by Nikitin (1890) at the base of the Rusavkino unit in a limestone near Gzhel village that disconformably overlies the Troshkovo unit of the Kasimovian (Ivanova and Khvorova, 1955). Makhlina et al. (1979) recognized four sedimentary cycles within the Rusavkino. However, more recently the Rusavkino has been divided into three cycles: Lower, Middle and Upper Rusavkino (Heckel et al., 2005). The conodonts *Streptognathodus zethus*, *St. firmus*, and *St. pawhuskaensis* are reported in the Lower and Middle Rusavkino, and *Streptognathodus simulator* is added to this assemblage in the Upper Rusavkino. The younger Amerevo unit contains the conodonts *St. ruzhenzevi* and *St. vitali* (Heckel et al., 2005). No fusulinids were shown for the Lower and Middle Rusavkino (although the presence of fusulinids in the lowermost Rusavkino was noted by Makhkina et al., 1979). *Rauserites rossicus* is recorded in the Upper Rusavkino, and *Rauserites stuckenbergi* in the Amerevo unit. Based on this observation, the FAD of *St. simulator* in the Usolka section at 4.9 mab corresponds to the Upper Rusavkino and the newly redefined base of the Gzhelian Stage (Heckel et al., 2005).

In the Usolka section (Fig. 2) the FAD of *St. simulator* is recorded within the evolutionary morphocline (Fig. 3): *Streptognathodus praenuntius* Chernykh, 2005 – *St. simulator* Ellison – *St. auritus* Chernykh within 2.7 m of beds 4 and 5. The undisturbed character of sedimentation in this interval and the data on conodont evolution suggest that there are no breaks in sedimentation during this transition, and allow the Usolka section to be considered as a candidate for the Global Stratotype Section and Point (GSSP) for the base of the Gzhelian Stage. *St. praenuntius* in the established chronocline has strong similarity to *S. simulator*, but differs from the latter in a less eccentric and less well developed trough along the medial line of the platform element (Fig. 2). The phylogenetic evolutionary relation between *Streptognathodus praenuntius* and *St. simulator* is proposed because: [1] these two species appear in successive order, and [2] there are numerous transitional forms from an almost undeveloped and nearly symmetric trough (assigned to *St. praenuntius*) to those with the clear and well-developed trough that is significantly

shifted toward one side of the platform (assigned to *St. simulator*). This trend indicates that *Streptognathodus praenuntius* is the most probable ancestor of *St. simulator*. A very similar trend in conodont evolution is observed in Midcontinent North America in the data of J. Barrick, D. Boardman and P. Heckel that was distributed among the Task Group members at the 2005 St. Petersburg meeting in Russia. “*Idiognathodus*” n. sp. aff. *I. simulator* from the Eudora Shale most probably belongs to *St. praenuntius* Chernykh. This species and *St. simulator* occur in North America in the same successive order as in the southern Urals. The next step in the evolutionary development of *Streptognathodus simulator* resulted in the appearance *St. auritus* Chernykh, 2005 (Fig. 3). The latter species has a slightly eccentric trough similar to *St. simulator*, but also has small nodes on one (inner) or both sides of the platform.

Conclusions

1. Although the proposed definition of the base of the global Gzhelian Stage, the FAD of *St. simulator*, is slightly above its traditional position in the Moscow region, this does not affect regional and interregional stratigraphy and correlation, and therefore would be supported and accepted by the geologic communities.
2. The Usolka section is one of the best candidates so far known for the GSSP that will define the global Gzhelian, although additional study is still required. No obvious interruptions in sedimentation are recorded within the Kasimovian-Gzhelian

transition there. The chronocline that defines the FAD of *St. simulator* is established within 20 cm of undisturbed sedimentary sequence. Several volcanic ash beds are present below and above the proposed boundary, making radiometric calibration highly possible in the near future (Schmitz et al., 2005).

3. Accessibility presently is adequate, and we have an agreement with the Bashkirian Academy of Sciences via the Institute of Geology in Ufa, Bashkortostan, Russia, that this exposure will be improved and maintained permanently for interested scientists. Future access will be guaranteed by means of legislative action to create a scientific preserve.
4. The relatively deeper water facies and the mode of preservation of conodonts with a CAI of around 1.0-1.5 suggest that chemostratigraphic and paleomagnetic studies would be highly possible. The first steps in this direction, Sr isotope studies, are already in progress (Needham et al., 2005).
5. A better relationship among conodont, fusulinid, and ammonoid biozonations and other fossil groups must still be worked out.

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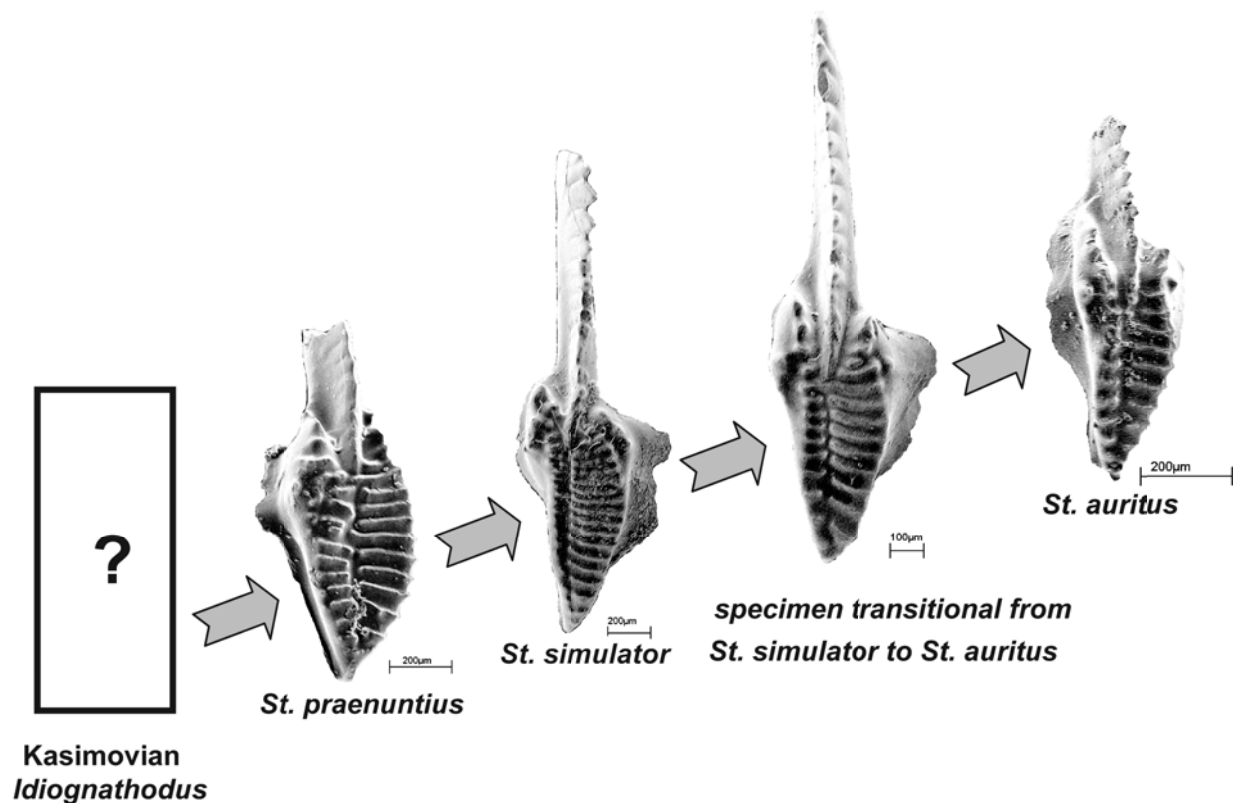


Figure 3. Evolutionary trend within chronocline of *St. simulator* and related species.

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Conodont and ammonoid distribution across position of proposed Kasimovian-Gzhelian boundary in lower Virgilian strata in North American Midcontinent

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Introduction

Because there is increasing interest in defining the global Kasimovian-Gzhelian Stage boundary at the first appearance of the conodont *Idiognathodus simulator* (Ellison, 1941) [sensu stricto] (Boardman and Work, 2004; Villa and Task Group, 2005; Heckel et al., 2005), it is appropriate to present the latest biostratigraphic information that has been obtained from Midcontinent North America, from which the holotype of *I. simulator* was described. Lower Virgilian conodonts spanning the position of the proposed Kasimovian-Gzhelian Stage boundary in the Midcontinent and north-central Texas have been reported by several authors, most recently Barrick and Boardman (1989), Boardman and Heckel (1989), Ritter (1994, 1995), Barrick and Walsh (1999), and Barrick et al. (2004). New data presented herein permit significant refinement in the stratigraphic distribution of species within the high-resolution glacial-eustatic sequence-stratigraphic [cyclothem] framework (Fig. 1). Additionally, two species are recognized as probably endemic, which minimizes their utilization in zonation schemes.

History of the placement of the provincial Missourian-Virgilian Stage boundary in the North American Midcontinent was summarized by Boardman et al. (1989; 1994). For purposes of this paper we follow Boardman et al. (1989), Heckel et al. (1999), Heckel and Watney (2002), and Barrick et al. (2004) in recognizing the base of the Virgilian Stage at the base of the Haskell Limestone Member of the Cass Limestone/cyclothem in the northern Midcontinent and the equivalent Colony Creek Shale in north-central Texas.

Biostratigraphy

Basal Virgilian conodonts from the Little Pawnee Shale (Fig. 2) in the major Cass cyclothem include *Streptognathodus zethus* Chernykh (Plate 1, fig. 14), *S. aff. zethus* (Plate 1, fig. 11), and *S. cf. holtensis* (Plate 1, fig. 12). This shale also yielded an *Idiognathodus* morphotype (Plate 1, fig. 13) that is transitional between older *I. aff. simulator* and younger *I. simulator* [sensu stricto]. *I. aff. simulator* occurs in the late Missourian Eudora Shale of the major Stanton cyclothem (Barrick et al. 2004, Pl. 5, fig. 10, p. 245) of the Midcontinent and the equivalent upper Winchell Limestone of Texas (Barrick and Boardman 1989, Pl. 3, figs. 15, 20, 21, p. 189), while *I. simulator* [s.s.] characterizes the Midcontinent Heebner Shale of the major Oread cyclothem (Barrick et al., 2004, Pl. 5, fig. 9, p. 245; this report, Plate 1, figs. 8-10) and the equivalent Finis Shale in Texas (Barrick and Boardman, 1989, Pl. 3, figs. 8, 9, 14, p. 189).

Ammonoids from the basal Virgilian include *Pseudaktubites stainbrooki* (Plummer and Scott) and *Eovidrioceras conlini* (Miller and Downs). These species are known from the Little Pawnee Shale of the Cass cyclothem in the Midcontinent and from the Colony Creek Shale in north-central Texas, which establishes correlation of these two units (Boardman et al., 1994; Boardman and Work, 2004).

Above the Cass, conodonts from the minor Amazonia cyclothem include only the long-ranging taxon *Streptognathodus pawhuskaensis* (Harris and Hollingsworth) (Plate 2, fig. 10). Conodonts from the next higher intermediate Toronto cyclothem include an apparent endemic *Streptognathodus* sp. A (Plate 2, figs. 8, 9), in addition to *S. pawhuskaensis*.

In the overlying major Oread cyclothem (Fig. 1), the condensed Heebner core shale (Fig. 2) is dominated by *Idiognathodus simulator* [s.s.], as it yielded the holotype for this taxon. It also contains *I. luganicus* (Kozitskaya) (Plate 1, fig. 7) as well as *S. pawhuskaensis*. The equivalent Finis Shale in north-central Texas contains *I. simulator* [s.s.] and *S. pawhuskaensis*.

Boardman et al. (1994) and Boardman and Work (2004) reported the ammonoid *Vidrioceras uddeni* Böse along with its probable ancestor *Eovidrioceras conlini* from the Heebner Shale. Additionally, they reported *V. uddeni* and *E. conlini* from the equivalent Finis Shale of north-central Texas. Significantly, the Finis also contains the appearance of the most morphologically primitive species of *Shumardites*, *S. cuyleri* Miller and Downs.

Conodonts from the Mid-Plattsmouth minor cycle, which is identified by a thin gray shale that represents a flooding surface in the regressive Plattsmouth Limestone above the Heebner, include the enigmatic *Streptognathodus bitteri* Ritter (Plate 2, fig. 7). This taxon is restricted to northern Kansas and northwestern Missouri. The younger intermediate Clay Creek cyclothem also contains *S. bitteri* (Plate 2, fig. 6), along with *Idiognathodus tersus* Ellison, *I. lobulatus* Kozitskaya, and *S. pawhuskaensis*. The next younger intermediate Spring Branch cyclothem contains *S. deflectus* Ritter (Plate 2, figs. 3, 4), *I. lobulatus* (Plate 2, fig. 5), *I. tersus*, and *S. pawhuskaensis*. *S. deflectus*, the probable descendant of *S. bitteri*, also is apparently endemic to northern Kansas and northwestern Missouri, because neither taxon has been found outside this area,

NORTH AMERICAN MIDCONTINENT

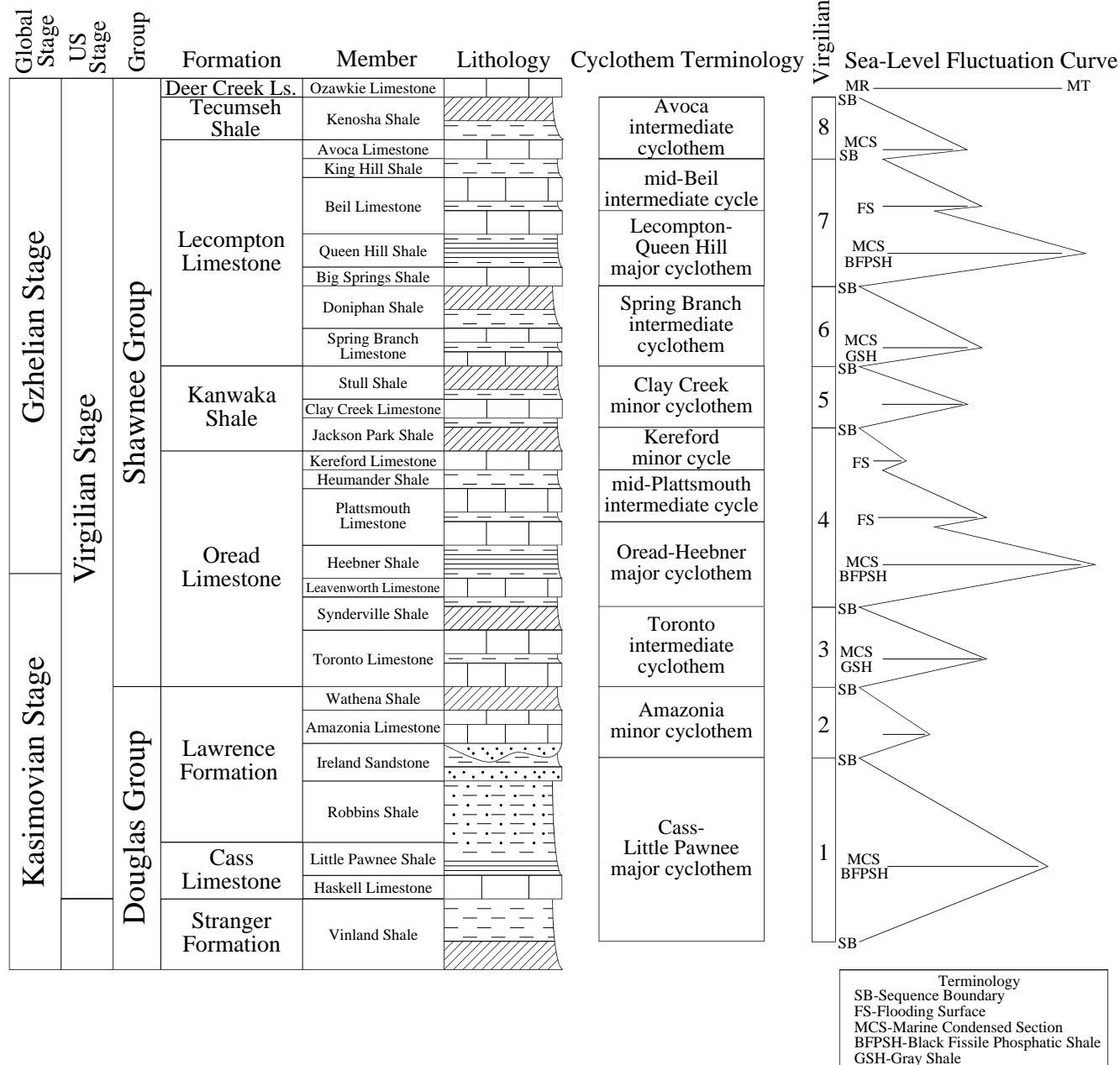


Figure 1. Columnar section of lower Virgilian strata in northern Midcontinent showing sea-level curve (modified from Heckel, 1986; Boardman, 1999), with cyclothems identified by name and sea-level fluctuation scale; minor fluctuations termed 'cycle' are parasequences.

NORTH AMERICAN MIDCONTINENT

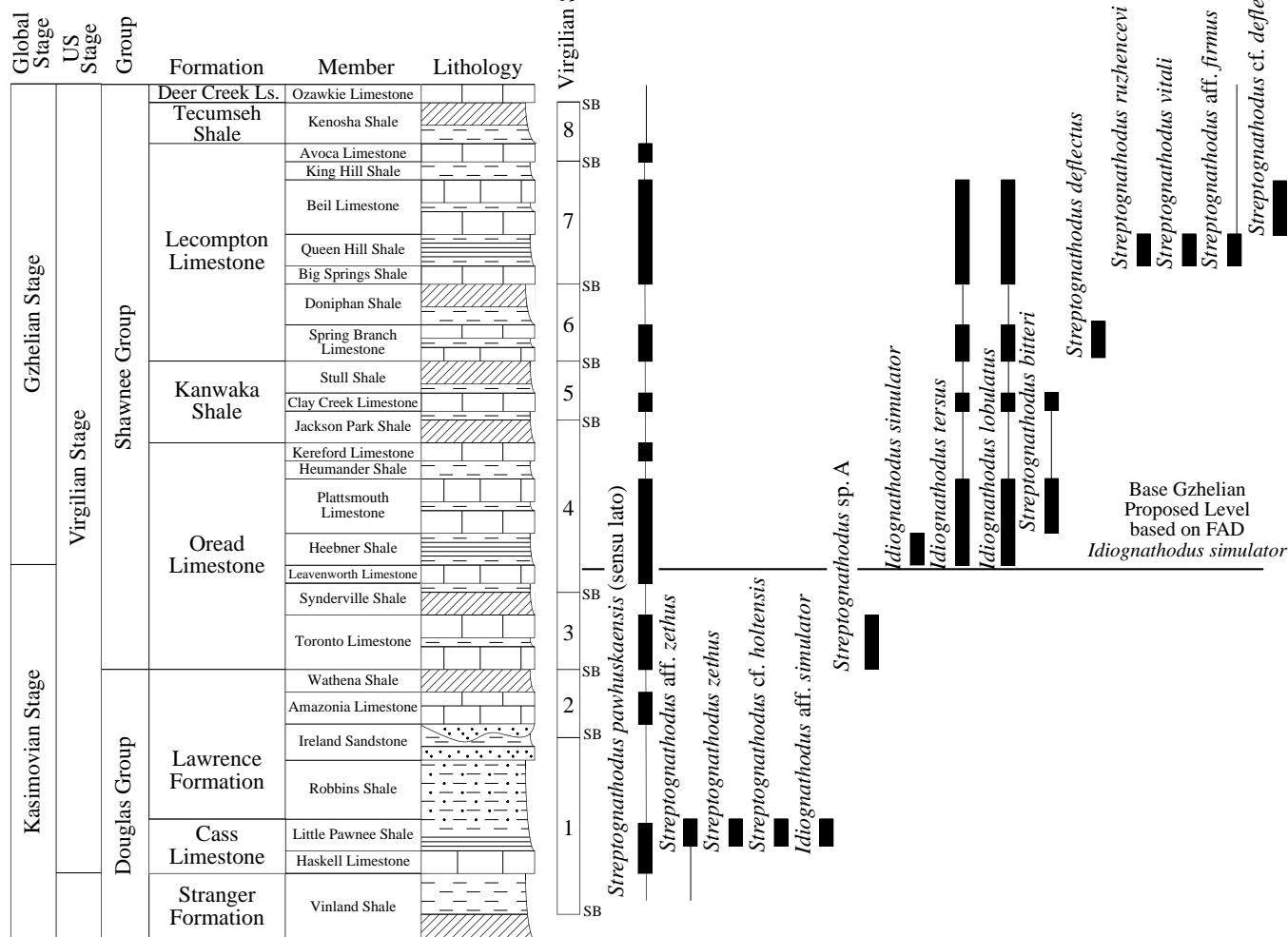


Figure 2. Columnar section of lower Virgilian strata in northern Midcontinent showing ranges of conodont taxa (modified from Barrick et al., 2004), and position of proposed global Kasimovian-Gzhelian Stage boundary.

nor in any of the core shales of the major cyclothem.

The next younger major cyclothem is the Lecompton (Figs. 1, 2). Its condensed core shale (Queen Hill) contains *Streptognathodus ruzhencevi* Kozur (Plate 1, fig. 5), *S. vitali* Chernykh (Plate 1, fig. 6), *S. aff. firmus* (Plate 1, fig. 4), *Idiognathodus tersus* (Plate 1, figs. 2, 3), and *I. cf. tersus* (Plate 1, fig. 1). Barrick and Boardman (1989) reported *S. ruzhencevi*, *S. vitali* (as *S. pawhuskaensis*), *I. tersus*, and *I. lobulatus* from the correlative Necessity Shale in north-central Texas.

Although ammonoids from the Queen Hill Shale in the Midcontinent are non-diagnostic, Boardman et al. (1994) reported *Shumardites simonds* (Smith), *S. cuyleri*, and *Vidrioceras uddeni* from the equivalent Necessity Shale in north-central Texas.

The highest conodonts illustrated in this report are from the Mid-Beil minor cycle, which is identified by a thin gray shale that represents a flooding surface in the regressive Beil Limestone

above the Queen Hill Shale. This interval yields *Streptognathodus cf. deflectus* (Plate 2, fig. 2) and *S. pawhuskaensis* (Plate 2, fig. 1).

Conclusions

The best levels for interbasinal and intercontinental correlation are provided by the deeper water species of *Idiognathodus* and *Streptognathodus* that are found in marine condensed sections [core shales] of major cyclothem. The three core shales studied for this report (Little Pawnee of the Cass cyclothem, Heebner of the Oread, and Queen Hill of the Lecompton) contain cosmopolitan species named from both North America and eastern Europe. Heckel et al. (2005) recognized correlatives to all three of these major cyclothem in the Moscow and Donets Basins in eastern Europe. In the Moscow Basin, the Lower Rusavkino cycle, which corresponds to the traditional base of the Gzhelian in that region, contains *Streptognathodus zethus*,

S. firmus, and *S. pawhuskaensis*, and thus correlates with the Cass cyclothem. The Upper Rusavkino cycle contains *Idiognathodus simulator* [s.s.], and thus correlates with the Oread cyclothem. The overlying Amerevo cycle contains *S. vitali* and *S. ruzhencevi*, and thus correlates with the Lecompton cyclothem.

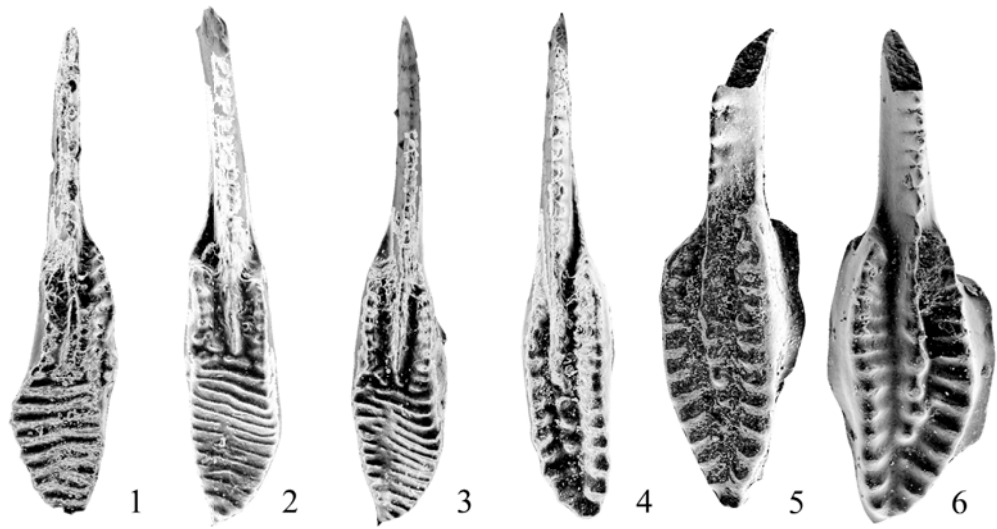
In the Midcontinent, minor and intermediate-scale cyclothems that lack black phosphatic shales are dominated by either long-ranging taxa or by apparently endemic forms such as *S. bitteri* and *S. deflectus*. These endemic forms are also common in minor cycles in regressive limestones, which are flooding surfaces that define parasequences above the core shales of the major cyclothems. The facts that these endemic forms have not yet been discovered in the core shales of the major cyclothems in the Midcontinent during current detailed work, and that they have not been reported from equivalent strata elsewhere in North America or eastern Europe, indicate that they are not useful for defining range zones that are helpful for global correlation.

We strongly support the first appearance of *Idiognathodus simulator* [s.s.] in the base of the Heebner Shale of the Oread cyclothem as the best position for the base of the global Gzhelian Stage (Fig. 1). This level is readily correlated among numerous localities in North America and with several sections in Eurasia (Heckel et al., 2005). Moreover, this level corresponds exactly to the base of the *Vidrioceras*–*Shumardites* ammonoid Genozone in both the Midcontinent and Texas, thereby providing additional support from another biostratigraphically useful group, for recognizing the first appearance of *I. simulator* [s.s.] as the best candidate for defining the base of the global Gzhelian Stage.

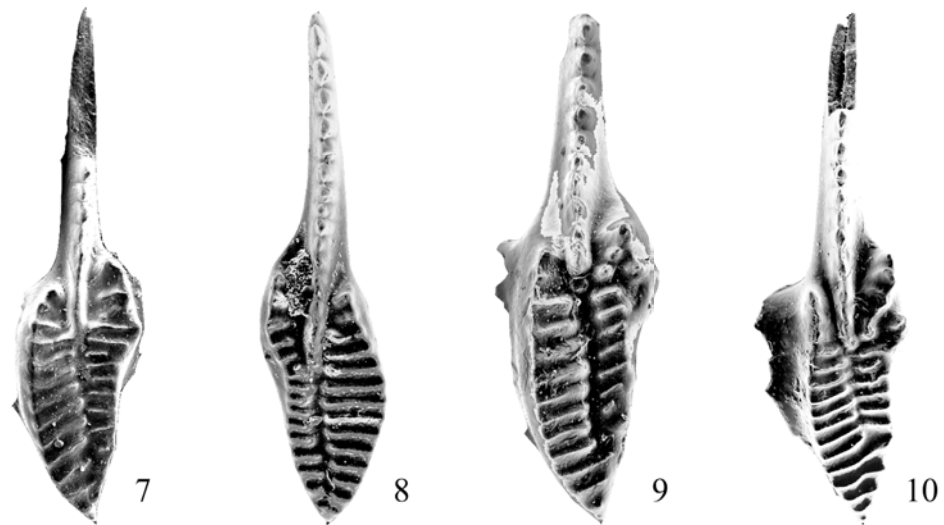
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Queen Hill
Shale of
Lecompton
cyclothem



Heebner
Shale of
Oread
cyclothem



Little Pawnee
Shale of Cass
cyclothem

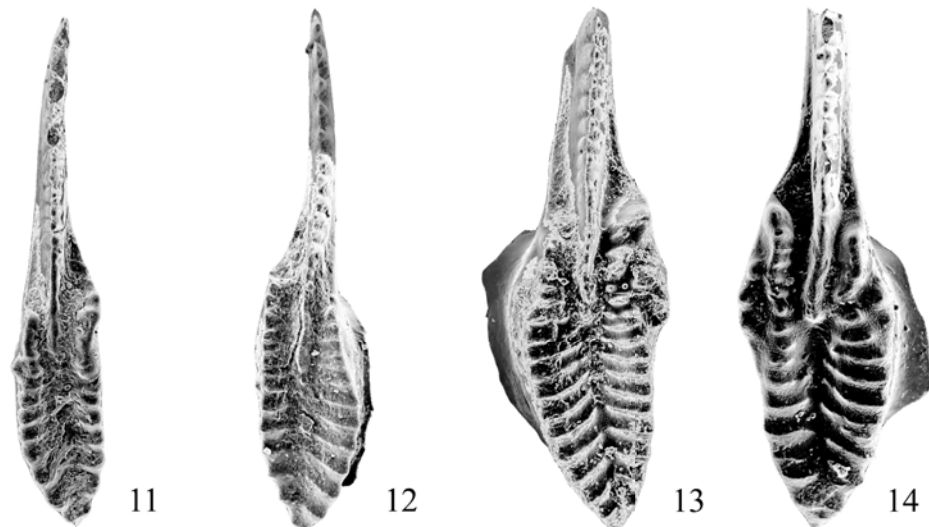
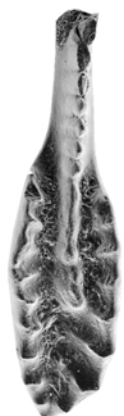


Plate 1. Conodonts from major cyclothems. 1-6.—Queen Hill Shale of Lecompton cyclothem; 1, *Idiognathodus* cf. *tersus* Ellison; 2, *Idiognathodus tersus* Ellison; 3, *Idiognathodus tersus* Ellison; 4, *Streptognathodus* aff. *firmus*; 5, *Streptognathodus ruzhencevi* Kozur; 6, *Streptognathodus vitali* Chernykh. 7-10.—Heebner Shale of Oread cyclothem; 7, *Idiognathodus luganicus* (Kozitskaya); 8, *Idiognathodus simulator* (Ellison); 9, *Idiognathodus simulator* (Ellison); 10, *Idiognathodus simulator* (Ellison). 11-14.—Little Pawnee Shale of Cass cyclothem; 11, *Streptognathodus* aff. *zethus*; 12, *Streptognathodus* cf. *holtensis*; 13, *Idiognathodus* aff. *simulator*; 14, *Streptognathodus zethus* Chernykh.

Mid-Beil cycle
[parasequence]
of Lecompton
major
cyclothem

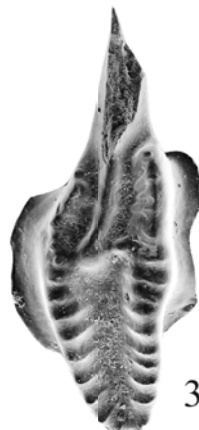


1



2

Spring Branch
intermediate cyclothem



3



4



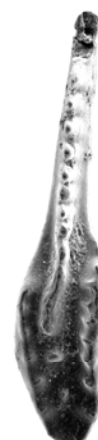
5

Clay Creek
intermediate
cyclothem



6

Mid-Plattsmouth cycle
[parasequence] of Oread
major cyclothem



7

Toronto
intermediate
cyclothem



8



9

Amazonia minor
cyclothem



10

Plate 2. Conodonts from cyclothem/cycles of lesser scale. 1-2.—Mid-Beil cycle[parasequence] of Lecompton major cyclothem; 1, *Streptognathodus pawhuskaensis* (Harris and Hollingsworth); 2, *Streptognathodus* cf. *S. deflectus*. 3-5.—Spring Branch intermediate cyclothem; 3, *Streptognathodus deflectus* Ritter; 4, *Streptognathodus deflectus* Ritter; 5, *Idiognathodus lobulatus* Kozitskaya. 6.—Clay Creek intermediate cyclothem; *Streptognathodus bitteri* Ritter. 7.—Mid-Plattsmouth cycle [parasequence] of Oread major cyclothem; *Streptognathodus bitteri* Ritter. 8-9.—Toronto intermediate cyclothem; 8, *Streptognathodus* sp. A; 9, *Streptognathodus* sp. A. 10.—Amazonia minor cyclothem; *Streptognathodus pawhuskaensis* (Harris and Hollingsworth).

Latest calibration of Middle to Late Pennsylvanian time scale using succession of Midcontinent cyclothems

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Introduction

My earlier attempts to calibrate the late Middle to Late Pennsylvanian time scale using glacial-eustatic cyclothems (Heckel, 2002, 2003, 2004) provided an evolving commentary on how the calibrations can vary with changes in the basic assumptions that are utilized in grouping the cyclothems of different scales as well as in determining how accurate the available radiometric dates are. Since then, recent reports of more precise radiometric dates from volcanic ash beds in the marine Pennsylvanian succession of the southern Urals (e.g., Schmitz et al., 2005) make it appropriate to present the most recent calibration and the assumptions that underlie it, along with their evolution from the previous attempts. Moreover, the recent recognition of minor geochemical cycles (Algeo et al., 2004) within the deep-water shale of a cyclothem and of minor lithostratigraphic cycles (Nadon and Kelley, 2004) within the high shelf shallow-marine equivalent of a deep-water shale provide promise of perhaps even more precise calibration of Pennsylvanian time. It is also worth noting that very recently, Joachimski et al. (2006) used oxygen isotope variation in apatite from conodonts collected from different depth zones in certain cyclothems to estimate that the amount of sea-level fluctuation related to glacial eustasy probably exceeded 100 m in the cyclothems of greatest magnitude, which supports the higher end of the range of opinion over the years on the amount of sea-level fluctuation during Late Pennsylvanian time.

Cyclothem Scale

The succession of cyclothems of various scales along the Midcontinent outcrop belt (Fig. 1) are classified as 'major,' 'intermediate,' and 'minor,' based on both their continuity along outcrop and the deepest-water facies developed at the northern limit of outcrop in Iowa toward the ancient cratonic shoreline. **Major cyclothems** are characterized by a widespread, conodont-rich, black phosphatic 'core' shale as the deepest-water facies, which developed only during the greatest highstands when a pycnocline caused anoxia to accompany sediment starvation on the sea bottom. **Intermediate cyclothems** contain only gray conodont-rich offshore shales or non-algal skeletal packstones, which represent sediment starvation without anoxia in water that was shallower, yet still deep enough for the unit to extend to the northern limit of outcrop. **Minor cyclothems** either extend only partway onto the shelf or represent reversal of sea-level trends in the more major cyclothems (and thus are termed simply 'cycles' as they represent only 'parasequences' in sequence-stratigraphic terminology). These typically lack conodont-rich zones or other evidence of sediment starvation, unless they were sea-level reversals in deeper water that brought sediment-starved facies above shallower-water carbonates. At maximum highstands, the sea was continuous across the entire central and eastern U.S.A. as shown by the great similarity of all marine faunas, particularly

the conodonts, which allow an accurate correlation of the major cyclothems across the entire region, and into the Illinois and Appalachian Basins (Heckel 1994). Most recently, Heckel et al. (2005) correlated the midcontinent cyclothems with those now recognized in the Moscow and Donets Basins, using a combination of cyclothem scale and conodont and fusuline faunas.

The empirical sea-level curve for the Midcontinent shelf (Fig. 1) shows that major cyclothems are spaced somewhat evenly throughout the succession, that most of them overlie widespread exposure surfaces, and that most are overlain by one or more intermediate or minor cycles following a regression of less distance than the transgression preceding the major cyclothem. This pattern of large-scale melting of ice sheets (transgression) followed by slower buildup of ice sheets (regression) with episodic minor melting phases before reaching maximum size (maximum lowstand) is somewhat similar to that seen in Pleistocene sea-level curves (e.g., Denton and Hughes, 1983; Lorius et al., 1993). There are as yet no discernable patterns of numerical groupings of 5 minor cycles that could readily be related to groupings of ~20-kyr precession cycles within the ~100-kyr short eccentricity cycles, or of 3 minor cycles that could be related to groupings of the ~34-kyr Pennsylvanian obliquity cycles (Berger et al., 1989) within the short eccentricity cycles. However, as minor cycles are still being discovered with continuing field and laboratory work, the data are not yet complete. Where the data are more complete among the larger cyclothems, there more definitely seems to be no consistent pattern of 4 intermediate cycles that could be related to groupings of short eccentricity cycles within the ~400-kyr long eccentricity cycles. Therefore, this empirical curve appears to represent an irregular integrated manifestation of the interaction of all the orbital parameters filtered through the complex systems of climate changes severe enough to result in buildup and melting of glacial ice sheets across large parts of the Gondwanan continent, which was modulated through the positions of climatic zones relative to positions of land masses and the resulting positions of ocean currents and temperature extremes. Thus, while an intermediate cyclothem might represent close to the 100-kyr period of a short eccentricity cycle, a major cyclothem probably represents the positive feedback of two or possibly three of the short eccentricity cycles within a long eccentricity cycle. However, we might still expect that approximately 20 minor cycles controlled predominantly by precession might be nested within a 400-kyr grouping that was controlled predominantly by the long eccentricity cycle.

Calibrations

To approach the problem of determining the major controls over Pennsylvanian cyclicity, Heckel (1986) initially made a series of assumptions about the ratios of the lengths of periods of the minor and intermediate cyclothems relative to the longer periods of the major cyclothems, and using the poorly constrained estimates of absolute dating at that time, he showed that the frequency of the Pennsylvanian cyclothems had to fall within the general 20-400-kyr range of the orbital parameters. More recently, Heckel (2002) assumed the accuracy of three radiometric age dates from the Appalachian succession that could be correlated approximately with the Midcontinent succession (where the record of cycles is much more complete), and he grouped the Midcontinent cycles into presumed 400-ky groupings that fit the three Appalachian dates. This placed the Pennsylvanian [Carboniferous]-Permian boundary

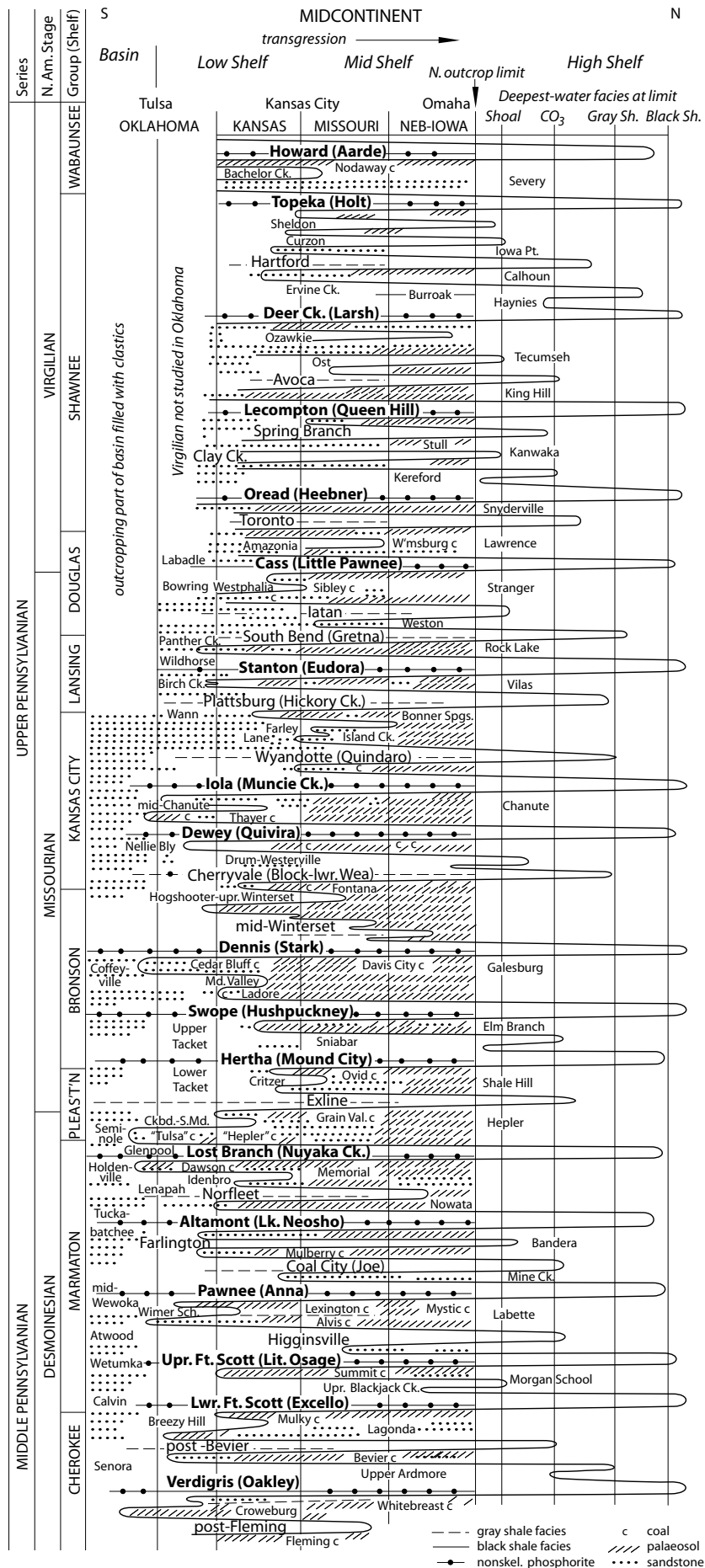


Figure 1. Sea-level curve for mid-Desmoinesian through mid-Virgilian succession showing all scales of cyclothems, classified as major, intermediate, or minor, based on lateral extent from Oklahoma foreland basin onto shelf and on deepest water facies at current northern limit on shelf, as denoted by decreasing boldness and letter size of names. Offshore (core) shale names are in parentheses, with black facies shown by solid lines, gray facies by dashed lines, with spots for nonskeletal phosphorite. Small dots indicate sandstones, and oblique lines on right side of curve indicate subaerial exposure with paleosol formation (updated from Heckel, 1994, and redrafted by A Strasser).

Figure 2. Chart showing most recent presumed 400-kyr groupings of Midcontinent cyclothems and minor transgressive-regressive units. Succession in Figure 1 is extended upward to base of Permian and downward to base of Desmoinesian based on data updated from Boardman (1999) and Boardman et al. (2002), respectively, and using cyclothem groupings of Olszewski and Patzkowski (2003) for upper Virgilian. Updated from Heckel (2004). Note that only Nemaha, Richardson, and Admire groupings in upper Virgilian do not contain a major cyclothem (hence are denoted in lower case letters), and that all other groupings contain only one major cyclothem along with the more minor cyclothems and cycles. Each of the other 400-kyr groupings is named for the major cyclothem that occurs within it. Plus sign [+] after name indicates recently determined presence of another minor transgressive-regressive cycle [or parasequence] within that unit. Current Moscovian-Kasimovian boundary shown in Figure 3 correlates with base of Farlington intermediate cyclothem at base of Altamont 400-kyr grouping (Heckel et al., 2005).

N.Am Reg. Stage	Cyclothems and other transgressive-regressive units of all scales	400-kyr cyclothem grouping
top Virgili an	Mid-Johnson Long Creek UPPER HUGHES CREEK Middle Hughes Creek Lower Hughes Creek + Americus Basal Americus	FORAKER [formation name] [III of O&P 2003, with 12 cycles]
	Upper Hamlin Lower Hamlin Five Point + West Branch Falls City +	Admire [group name] [II of O&P 2003, with 9 cycles]
	Aspinwall Brownville Grayhorse Nebraska City French Creek Jim Creek Grandhaven Dover-Dry	Richardson [subgroup name] [I of O&P 2003, with 8 cycles]
	Maple Hill Wamego Tarkio Elmont Reading Wakarusa + Burlingame	Nemaha [subgroup name]
	Silver Lake Rulo Happy Hollow White Cloud Winzeler HOWARD [Shanghai Ck/Aarde]	HOWARD
	Bachelor Creek TOPEKA [Holt] Mid-Dubois Sheldon	TOPEKA
	Curzon Hartford + DEER CK [Larsh-Burroak] + Ozawkie	DEER CREEK
	Ost Avoca Mid-Beil LECOMPTON [Queen Hill] Spring Branch	LECOMPTON
	Clay Creek Kereford/Elgin Mid-Plattsmouth OREAD [Heebner] Toronto	OREAD
base Virgili an	Amazonia CASS [Little Pawnee] Westphalia	CASS
top Misso urian	Iatan South Bend [Gretna] STANTON [Eudora] Birch Creek Plattsburg [Hickory Creek]	STANTON
	Upper Farley Lower Farley Wyandotte [Quindaro] IOLA [Muncie Creek] Mid-Chanute	IOLA

	Upper Cement City DEWEY [Quivira] Drum-Westerville Cherryvale [Block-Wea] Hogshooter-upper Winterset	DEWEY
	mid-Winterset +++ DENNIS [Stark]	DENNIS
	Mound Valley Mid-Bethany Falls SWOPE [Hushpuckney]	SWOPE
	Sniabar HERTHA [Mound City] Critzler Exline Checkerboard-South Mound	HERTHA
top Desm oines ian	Glenpool LOST BRANCH [Nuyaka Ck]	LOST BRANCH
	Ideenbro Norfleet ALTAMONT [Lake Neosho] Amoret Farlington	ALTAMONT
	Coal City [Joe] LOWER PAWNEE [Anna] Wimer School/Sageeyah	PAWNEE
	Higginsville UPR FT SCOTT [Little Osage]	UPPER FORT SCOTT
	Upper Blackjack Creek LOWER FT SCOTT [Excello] Breezy Hill	LOWER FORT SCOTT
	Post-Bevier Post-Wheeler Upper Ardmore VERDIGRIS [Oakley] Post-Fleming Post-Robinson Branch	VERDIGRIS
	Russell Creek / Post-Mineral UPR TIAWAH / Post-Scammon? Lower Tiawah/Post-Tebo Post-RC Coal Post-Weir-Pittsburg Uppermost Boggy Post-Wainwright	TIAWAH
	INOLA Post-Peters Chapel Post-Secor Rider Post-Secor Post-Lower Witteville	INOLA
	Post-Drywood DONELEY / POST-ROWE Sam Creek Post-Tallahassee Spaniard	DONELEY
base Desm oines ian	Post-Keota Post-Tamaha Post-Stigler Post-Warner Post-Keefton McCURTAIN	McCURTAIN

MAJOR CYCLOTHEM [core shale]; Intermediate cyclothem; Minor cycle; + = additional minor cycle present

CYCLOTHEM CALIBRATION OF MIDDLE-LATE PENNSYLVANIAN SUCCESSION IN MIDCONTINENT NORTH AMERICA

Boundaries and N. American stages / [Global stages]	Estimated dates of Gradstein et al. (2004)	Number of 400-kyr cyclothem groupings in stage	Duration of stage, based on number of groupings	Boundary calibration, Ma (compared w. *precise radiometric dates in bold)
<u>Carboniferous-Permian boundary</u>	299.0 Ma			<u>298.6 Ma (calibrated C-P bdy)</u> (*298.4 ± 0.2, U-Pb, Urals)
Virgilian Stage [~Gzhelian Stage]		10	4.0 myr	
<u>Missourian-Virgilian bdy</u> [~Kasim.-Gzhelian bdy]	303.9 [K-G bdy]			<u>302.6 Ma (calibrated M-V bdy)</u>
Missourian Stage [~Kasimovian Stage, except base]		6 [Kasimovian ~8]	2.4 myr [Kasimovian ~3.2]	
<u>Desm.-Missourian bdy</u> [two 400-kyr groupings above Moscovian-Kasimovian boundary]	306.5 [M-K bdy]			<u>305 Ma (calibrated D-M bdy)</u> [calibrated M-K bdy ~305.8] (*305.4 ± 0.2, U-Pb, Urals)
Desmoinesian Stage [~late Moscovian]		10 [late Moscovian ~8]	4.0 myr [late Moscovian ~3.2]	
<u>Atokan-Desmoines. bdy</u> mid+late Atokan Stage [~early Moscovian]		(cycles not identified)	(assumed ~2 myr)	<u>309 Ma (assumed A-D bdy)</u>
<u>early-mid Atokan bdy</u> [~Bashkirian-Mosc. bdy]	311.7 [B-M bdy]			(*311 ± 1.0, Ar/Ar, Appalachians)
Total Desm.-Virgilian		26	10.4 myr	

Figure 3. Chart showing most recent calibration of Middle-Late Pennsylvanian time scale using presumed 400-kyr cyclothem groupings within North American stages from Figure 2 and more current and precise radiometric U-Pb zircon dates from correlated sections in southern Urals (Schmitz et al., 2005; V. Davydov, personal communication, 2005), plus older Appalachian Ar/Ar sanidine date of Kunk and Rice (1994), all in right-hand column. Updated from Heckel (2003), and showing estimated dates of Gradstein et al. (2004) for global stage boundaries in second column. This cyclothem calibration assumes relative accuracy of 311 ± 1.0 Ma Appalachian Ar/Ar sanidine date, estimated 2 myr duration of mid and late Atokan Stage, and relative accuracy of 400-kyr cyclothem groupings for North American stages in Figure 2. Match of cyclothem-calibrated 298.6 Ma Carboniferous-Permian boundary date is very close to precise 298.4 ± 0.2 Ma southern Urals U-Pb zircon date for that boundary, and match of calibrated 305.8 Ma current Moscovian-Kasimovian boundary (two 400-kyr groupings below calibrated 305 Ma Desmoinesian-Missourian boundary) is quite close to precise 305.4 ± 0.2 Ma southern Urals U-Pb zircon date just below current Moscovian-Kasimovian boundary.

at ~290 Ma, where Harland et al. (1990) had estimated it. This grouping resulted in 45 presumed 400-kyr groupings, 17 of which contained only minor and intermediate cyclothems, and 7 of which comprised only a single major cyclothem. Later, Heckel (2003) assumed the accuracy of the 296-Ma age of the C-P boundary estimated by Menning et al. (2000), that the older Appalachian sanidine Ar/Ar date of Kunk and Rice (1994) is more accurate than the younger U-Pb calcite dates of Becker et al. (2001), and he regrouped the Midcontinent cycles into 30 presumed 400-kyr groupings, only 5 of which contained no major cyclothems, and only two of which comprised only a single major cyclothem. Then, Heckel (2004) assumed that the most recent estimates and precise radiometric dates closer to 299 Ma (see below) are more accurate for the C-P boundary, and he again regrouped the cycles into 26 presumed 400-ky groupings, of which only 3 (in the late Virgilian) contain no major cyclothems and none comprise only a single major cyclothem (Fig. 2). Subsequently, Heckel reduced the assumed duration of the middle and late Atokan (pre-Desmoinesian) section above the most accurate Appalachian date (Kunk and Rice, 1994) from 3 myr to 2 myr, and came even closer (298.6 Ma) to the more recent estimate (299 Ma) of Gradstein et al. (2004) for the C-P boundary (Fig. 3). The most recent, more precise U-Pb zircon dates from the marine succession in the southern Urals (Schmitz et al., 2005; V. Davydov, personal communication, 2005)

place the C-P boundary at 298.4 ± 0.2 Ma. Moreover, they place a tuff bed near the current top of the Moscovian at 305.4 ± 0.2 Ma, which is about two presumed 400-kyr groupings below the 305-Ma cyclothem-calibrated date for the Desmoinesian-Missourian boundary (Fig. 3). This near coincidence of two precise dates from the same lab correlated with the current 400-kyr midcontinent cyclothem grouping (Fig. 2) shows that the calibration of this part of the Pennsylvanian time scale is becoming more accurate.

In the meantime, Algeo et al. (2004) identified about 12 cycles of geochemical variation (TOC, total S, total P, among other parameters) within the undisturbed black facies of the Hushpuckney Shale of the major Swope cyclothem in Kansas, which contains only two other field-identified minor cycles in its grouping (Fig. 2). This would bring the total number of minor cycles recognized within this grouping to 14, much closer to the 20 minor precession cycles that might be expected within a 400-kyr grouping, most of them ‘hidden’ in the deep-water black shale facies on the lower shelf. Moreover, in the Appalachian Basin in eastern Ohio, Nadon and Kelly (2004) discovered 5 minor cycles defined by minor sequence boundaries and paleosols on outcrop within the Ames marine interval, which is correlated with the major Oread cyclothem in the Midcontinent. These high-shelf minor cycles appear to represent minor cycles that are presumably also ‘hidden’ in the offshore condensed interval of the equivalent

black Heebner Shale of the Oread cyclothem in the Midcontinent. These studies show that at least some of the ‘missed beats’ of Goldhammer et al. (1990) can be identified at particular elevations on the shelf where lithic facies were conspicuously affected by minor sea-level changes or where geochemical proxies recorded the changes within the same general lithic facies, such as black shale.

Conclusions

Even though the Pennsylvanian time scale seems to be approaching greater accuracy with the more precise radiometric dates from correlated marine units, and with calibration by more reasonably constrained 400-kyr cyclothem groupings, we must continually keep in mind the assumptions that we make with all aspects of the data that are available. The progression of estimates from 2002 to 2004 involved changing the assumptions from 3 accurate Appalachian dates (2002), to an accurate 296 Ma C-P boundary date plus only one accurate Appalachian date (2003), to an accurate 299 Ma boundary date (2004) plus one accurate Appalachian date. The current estimate still rests upon the additional assumptions of the accuracy of the oldest Appalachian sandine date and of the reduced time-interval between it and the lowest Desmoinesian cyclothem, but the near match of the late Moscovian date with its correlated position in the Midcontinent is very encouraging. Moreover, recent detection of possibly precession-controlled geochemical cycles within a deep-water shale on the low shelf, plus minor sea-level changes on the high shelf within a shallower-water equivalent to a deep-water shale, suggest that even greater precision of calibration will eventually be possible.

Acknowledgments

In addition to many colleagues with whom I have discussed many of these issues, especially Tom Algeo and Greg Nadon, I thank Vladimir Davydov, who provided the recent precise radiometric U-Pb zircon dates from the southern Urals obtained from his colleagues at Boise State University, and Andre Strasser, who organized and first-authored a paper on cyclostratigraphy for the ISSC of the ICS, from which my contribution formed the basis of this paper.

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Kasimovian and Gzhelian (Upper Pennsylvanian) conodont zonation in Russia

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Introduction

Kasimovian and Gzhelian shallow-water sediments are widely distributed in the Moscow Basin, especially in the southern part where the type sections of the Kasimovian and Gzhelian Stages are situated. The older conodont zonations for central Russia (Barskov and Alekseev, 1975; Barskov, 1984; Barskov et al., 1984) cannot easily be used outside the East-European Platform due to regional discrepancies and strong facies control over the distribution of the most important species. During the last several years, significant advances have been made in understanding the stratigraphic distribution of conodonts in this region and in deep-water successions of the South Urals. More than 50 sections in total have received study or restudy with closely spaced sampling. They have been reliably correlated with each other on lithostratigraphic and biostratigraphic bases. Recently, Chernykh (2002) published a zonation for the Gzhelian of the South Urals. As a result, we propose a new zonation of the Kasimovian–Gzhelian interval that is applicable to central Russia as well (Fig. 1).

The Kasimovian part of the zonation includes 7 zones (*subexcelsus*, *makhlinae*, *sagittalis*, *cancellosus*, *toretzianus*, *firmus*, and *zethus*) established in the Moscow Basin. The Gzhelian succession contains 5 zones (*simulator*, *vitali*, *virgicus*, *bellus*, and *wabaunsensis*). Only the lower part of the Gzhelian is well exposed and characterized by conodonts in the Moscow Basin. Therefore the zonation of the rest of the Gzhelian was established on the basis of conodont distribution in the South Urals sections (Chernykh, 2000, 2002). All subdivisions of the scheme are interval-zones, with the lower boundaries defined by the first appearance of the index species.

Kasimovian Stage

The *subexcelsus* Zone (Alekseev and Goreva, 2000; Makhlina et al., 2001) was named for *Streptognathodus subexcelsus* Alekseev and Goreva, 2001. Characteristic Bashkirian and Moscovian species of the genus *Neognathodus* are lacking in the *subexcelsus* Zone of the Moscow Basin, but are still present in that interval in the South Urals. In the Moscow area, the middle part of the zone is marked by the first appearance of *Idiognathodus fischeri* Alekseev and Goreva and the last occurrence of the latest representatives of the *I. delicatus* group. This zone corresponds to the lower part of the Krevyakinian Substage (Suvorovo Formation) and the lower part of the *Protriticites pseudomontiparus*–*Obsoletes obsoletus* fusulinid Zone (Makhlina et al., 2001).

The *subexcelsus* Zone is recognized in the Donets Basin and South Urals as well (Alekseev et al., 2002)

The *makhlinae* Zone (Alekseev and Goreva, 2000; Makhlina et al., 2001) was named for *Streptognathodus makhlinae* Alekseev and Goreva, 2001. At present this species should be assigned to the genus *Swadelina* (Lambert et al., 2003). In the Moscow Basin and the South Urals the *makhlinae* Zone contains a characteristic species *Idiognathodus trigonolobatus* Barskov and Alekseev. In the Moscow area, the *makhlinae* Zone is referred to the upper part of the Krevyakinian Substage (Voskresensk Formation) and the basal part of the Khamovnikian Substage (lower part of Ratmirovo Formation). The upper Ratmirovo and basal to lower Neverovo Formation do not contain *S. makhlinae*, and are only arbitrarily included in the *makhlinae* Zone. The lower Neverovo conodont fauna is dominated by *Streptognathodus neverovensensis* Goreva and Alekseev. It corresponds to the upper part of the *Protriticites pseudomontiparus*–*Obsoletes obsoletus* fusulinid Zone and the basal part of the *Montiparus montiparus* fusulinid Zone.

The *makhlinae* Zone is readily recognized in the Moscow area (Makhlina et al., 2001), Middle Volga region (Sungatullina, 2002), South Urals (Alekseev et al., 2002), and Novaya Zemlya (Sobolev and Nakrem, 1996).

The *sagittalis* Zone was first established as the *Idiognathodus sagittalis* Subzone (Barskov et al., 1982, 1984), and was named for *Idiognathodus sagittalis* Kozitskaya, 1978. The morphologically distinctive index species is widespread (Alekseev and Goreva, 2002, 2003). In the Moscow Basin, the *sagittalis* Zone corresponds to the middle part of the Khamovnikian Substage (middle Neverovo Formation), where the typical/advanced forms of the fusulinid *Montiparus* first appear.

In addition to the Donets Basin, where it was first described, and the central Russian Platform, *Idiognathodus sagittalis* is found in the Volga-Ural region (Sungatullina, 2002), South Urals (Alekseev, Goreva, 2002), northern Timan (Goreva et al., 1997), northern Spain, and Midcontinent USA (Heckel et al., 2005).

The *cancellosus* Zone (Barrick and Heckel, 2000) was named for *Streptognathodus cancellosus* (Gunnell, 1931). It appears that this index species does not reach the top of the zone where it is substituted in the Moscow Basin by forms with reduced lateral lobes (*S. aff. cancellosus*). In the Moscow Basin, the *cancellosus* Zone corresponds to the uppermost part of the Khamovnikian Substage (upper Neverovo Formation) and the lower part of the Dorogomilovian Substage (Perkhurovo Formation), i.e., to the upper part of the *M. montiparus* fusulinid Zone and basal part of the *Rauserites quasiarcticus* fusulinid Zone.

The *toretzianus* Zone was first established as the *Idiognathodus toretzianus* Subzone (Barskov et al., 1982, 1984), and was named for *Idiognathodus toretzianus* Kozitskaya, 1978. In the Moscow sections the index species is associated with the primitive morphotype of *Streptognathodus isakovae* Goreva and Alekseev (2006) and a typical *Idiognathodus magnificus* Stauffer and Plummer. This allows approximate correlation between the *toretzianus* Zone and the *magnificus* Zone of the Midcontinent USA (Barrick and Heckel, 2000). In the Moscow Basin the lower part of the *toretzianus* Zone contains *Idiognathodus mestsherensis* Alekseev and Goreva (locally the *mestsherensis* Zone). This

termed *S. aff. zethus*. In the Moscow region, the zone is an equivalent of members 2 and 3 of the Rusavkino Formation. The *firmus* Zone corresponds either to the uppermost part of the *R. quasiarcticus* fusulinid Zone or to the basal part of the *Triticites rossicus*–*R. stuckenbergi* fusulinid Zone. The local *zethus* Zone was established by Alekseev and Goreva (2000) in the lower part of the Rusavkino Formation of the Moscow Basin. This zone was named for *Streptognathodus zethus* Chernykh and Reshetkova, 1987 and is characterized also by frequent *S. firmus* and rare forms of the *I. toretzianus* group. In the Moscow Basin, the *zethus* Zone is restricted to a very narrow stratigraphic interval, i.e., member 3 of the Rusavkino Formation of the Dobryatinian Substage and, hence, to some part of the *Triticites rossicus*–*R. stuckenbergi* Zone.

The *firmus* Zone can be traced in the central Russian Platform, the Donetsk Basin, the Volga-Ural region, and the South Urals.

Gzhelian Stage

The *simulator* Zone (Barskov et al., 1982, 1984) was named for *Idiognathodus* (*Streptognathodus*) *simulator* (Ellison, 1941) [s.s.]. Its lower boundary is defined by the first occurrence of the typical forms of this species. The zonal assemblage includes *I. luganicus* (Kozitskaya), *S. pawhuskaensis* Harris and Hollingsworth [= *S. alekseevi* Barskov et al.], *Idiognathodus tersus* Ellison and other forms.

The *simulator* Zone embraces member 5 of the Rusavkino Formation and, probably, the overlying terrigenous Stshelkovo Formation. It corresponds to part of the *Triticites rossicus*–*R. stuckenbergi* fusulinid Zone, and it can be traced in the central Russian Platform, Donetsk Basin, South Urals, and Midcontinent USA (Heckel et al., 2005).

The *vitali* Zone (Chernykh, 2002) was named for *Streptognathodus vitali* Chernykh, 2002. The zonal assemblage includes the index species, along with *S. pawhuskaensis* Harris and Hollingsworth, *S. simulator* Ellison, and *S. ruzhencevi* Kozur. The overlying limestones and dolostones of the Upper Dobryatinian Amerevo (Turabievo) Formation contain rare conodonts of the *vitali* Zone. This stratigraphic interval and the overlying Pavlovoposadian Substage were previously assigned to the *Streptognathodus ruzhencevi* Zone. The *vitali* Zone is correlative with the upper part of the South Urals *Daixina fragilis* fusulinid Zone and most of the *Triticites rossicus*–*R. stuckenbergi* Zone.

The *vitali* Zone has been recognized up to now only in the central Russian Platform, Volga-Ural region, and the South Urals. Heckel et al. (2005) report *S. vitali* from strata above those with *I. simulator* in Midcontinent USA.

The *virgilicus* Zone (Ritter, 1995) was named for *Streptognathodus virgilicus* Ritter, 1995. The stratigraphic interval of this zone was reliably defined in the South Urals, where it embraces the uppermost part of the *Triticites rossicus*–*R. stuckenbergi* Zone, the *Jigulites jigulensis* Zone, and the basal part of the *Daixina sokensis* Zone (Chernykh, 2002). Herein this stratigraphic interval is enlarged by including the *simplex* Zone of Chernykh. In the Moscow Basin, *S. virgilicus* occurs in the

lower part of the Pavlovoposadian Substage on the eastern slope of the Oka-Tsna Swell.

The *virgilicus* Zone is reliably recognized in the South Urals and central Russian Platform.

The *bellus* Zone (Chernykh, 2000) was named for *Streptognathodus bellus* Chernykh and Ritter, 1997. In the South Urals, the conodont fauna of this zone includes *S. longilatus* Chernykh and Ritter, *S. costaeiflabellus* Chernykh and Ritter, and *S. tenuialveus* Chernykh and Ritter. Based on the South Ural sections, the *bellus* Zone can be correlated with the upper part of the *Daixina sokensis* fusulinid Zone. In the Moscow region, the index species is found on the Oka-Tsna Swell in the Noginskian Substage.

The *bellus* Zone is traced in the central Russian Platform, Volga-Ural region, and South Urals.

The *wabaunsensis* Zone was first established by Barskov (1984) as the lowermost zone of the Asselian (Lower Permian), but this interval is now regarded as the uppermost part of the Gzhelian. This zone was named for *Streptognathodus wabaunsensis* Gunnell, 1933. There are also *S. elongatus* Gunnell, *S. simplex* Gunnell and some other species of this genus in this zone.

In the South Urals and Moscow Basin, the *wabaunsensis* Zone is an equivalent of the *Daixina bosbytauensis*–*D. robusta* Zone (Melekhovian Substage) (Makhlina and Isakova, 1997). The *wabaunsensis* Zone is widely traceable in the central Russian Platform, South Urals, Donetsk Basin, and western Kazakhstan.

Conclusions

The more thorough study of conodont distribution in the type and reference sections of the central Russian Platform and the South Urals in combination with the analysis of previous data on the Gzhelian of the South Urals allows us to develop a zonal scheme that was accepted as part of the general Carboniferous conodont scale for Russia (Kagarmanov and Kossovaya, 2003). The scheme can be used over the entire Russian Platform and the Urals from Novaya Zemlya in the north to Mugodzhary in the south. These regions are the main areas where Pennsylvanian marine deposits crop out in Russia. Recently, Pennsylvanian conodont zonations were published for Midcontinent USA (Barrick et al., 2004) and South China (Wang and Qi, 2003). Davydov et al. (2004) proposed a conodont zonation for the Carboniferous System as a global standard, but only number symbols are shown without explanations. Eight zones were proposed in studied interval: Pc12–Pc19. Three marker events (first appearances) are mentioned: *Idiognathodus sagittalis* (base of zone PC 13), *Streptognathodus* “*simulator*” [sic] (base of Pc15), and *Streptognathodus wabaunsensis* (base of Pc19). Absence of detailed information does not permit objective comparison of the Moscow Basin zonation with that of Davydov et al. (2004).

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