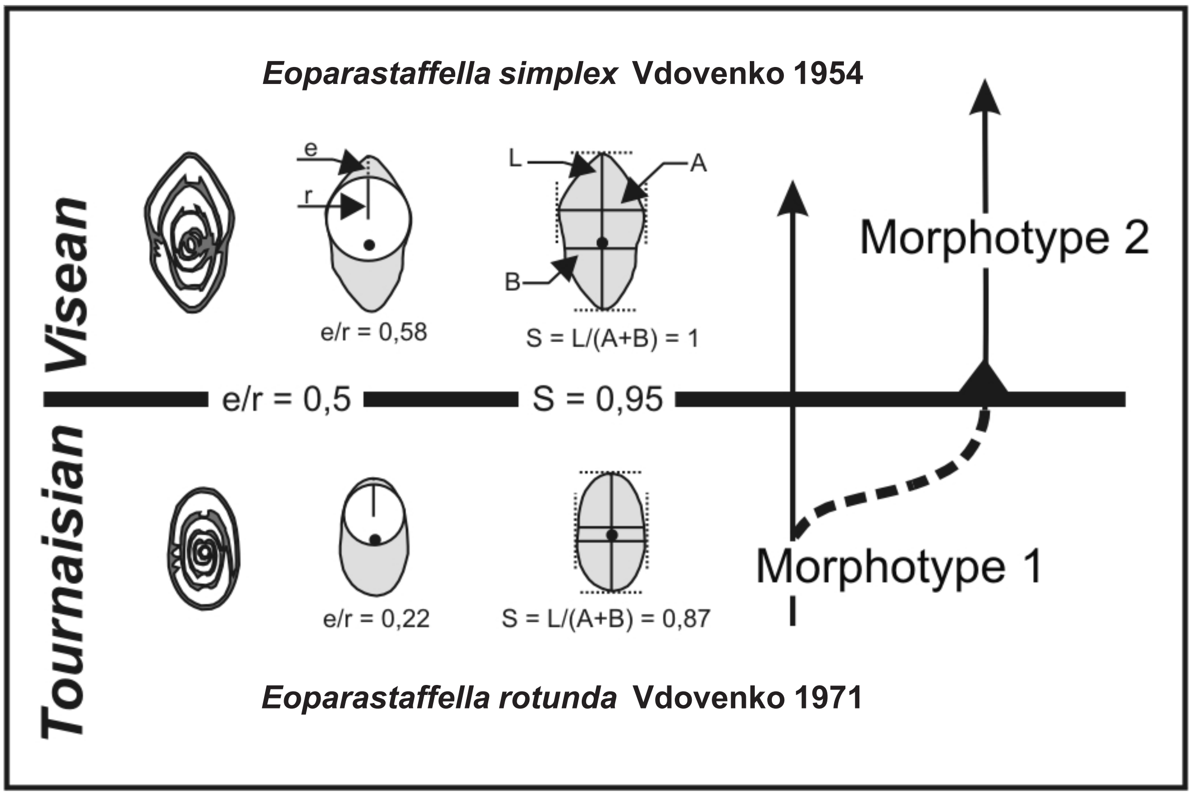
NEWSLETTER ON CARBONIFEROUS STRATIGRAPHY

Volume 21 July 2003



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

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Newsletter on Carboniferous Stratigraphy

Edited by D.M. Work

IUGS SUBCOMMISSION ON CARBONIFEROUS STRATIGRAPHY / VOL. 21 - 2003

CHAIRMAN'S COLUMN

This year has seen much more progress toward defining boundaries between the stages of the Carboniferous System. At this time, we are looking forward to the 15th International Congress on the Stratigraphy and Geology of the Carboniferous and Permian Systems [XV-ICCP] to be held in Utrecht, the Netherlands, during the week of August 11-15, 2003. At this meeting there will be a Carboniferous workshop on Wednesday, August 13, at which all boundary task groups will meet in adjacent rooms equipped with poster and layout space, projection equipment, and microscopes for examining conodonts and forams. In the past several years, I have found that this type of meeting of the task group to which I belong has been very fruitful for interchange of information, ideas, and particularly for achieving common ground on the recognition of the fossil taxa that are critical for defining boundaries. On Friday morning, August 15, there will be a meeting of the Subcommission on Carboniferous Stratigraphy, where we can discuss the results of the workshops and other issues of interest to Carboniferous stratigraphers.

Status of Boundary Task Groups

The Tournaisian-Viséan Boundary Task Group chaired by George Sevastopulo is putting the finishing touches on its proposal for the base of the Viséan at the Pengchong section in Guangxi, southern China. The Task Group to establish a GSSP close to the existing Viséan-Serpukhovian Boundary chaired by Barry Richards has 20 members and is summarizing the current state of knowledge on useful biotic lineages, potentially useful sequence-stratigraphic, chemostratigraphic, magnetostratgraphic and other physical events, and the locations of essentially continuous, fossiliferous marine successions that are readily accessible. The Task Group to establish a GSSP close to the existing Bashkirian-Moscovian Boundary chaired by John Groves has 17 members and is compiling lists of potentially useful biotic lineages, physical and chemostratigraphic events, and basins where continuous sections exist. The Task Group to establish a GSSP close to the Moscovian-Kasimovian Boundary chaired by Elisa Villa held a meeting during August 2002 in Ufa, Russia, where they visited possible candidate sections in the southern Urals, and where the Russian conodont workers reported the possibility that a lineage involving *Idiognathodus sagittalis* may be useful in defining the boundary. A subsequent meeting of Russian, Ukrainian, and American conodont workers in Moscow in May-June 2003 further evaluated this possibility and concluded that *I. sagittalis* occurs in Midcontinent North America and the Moscow and southern Urals regions of Russia, as well as in the Donets Basin of Ukraine from which it was named. Thus more activity is planned on refining the taxonomy of the lineage and identifying the accompanying fossils of other important groups. This same meeting in Moscow also discussed possible conodont lineages for defining the Kasimovian-Gzhelian boundary, which is also included in the responsibilities of this task group. More detail on the activities of the boundary task groups follows the introductory portion of this Newsletter. In addition, the Project Group on Comparative Angara and Gondwana Biostratigraphy chaired by Marina Durante is working on a paper 'Upper Paleozoic boreal biota: Stratigraphy and paleogeography.' This group has seven members who are working on various fossil groups [including brachiopods, small forams, pelecypods, and plants] as well as the stratigraphy of northern and northeastern Russia and Mongolia.

Stage and Series Subdivision

I have received very little formal feedback on my discussion of stages and series in the Carboniferous. What I have heard informally strongly supports the idea of relatively few stages, that is, a similar number of stages as exist in the Devonian and Permian, and certainly far fewer than exist in the northwest European regional classification of the Carboniferous. At present, there are task groups working on stage boundaries for five stages in addition to the two that have already been established by the Devonian-Carboniferous and Mid-Carboniferous boundaries, for a total of seven. One of the issues to be dealt with at the SCCS meeting in Utrecht will be to reduce the rank of the 7 Namurian and 3 Westphalian stages that were formally approved in 1989 [see Wagner and Winkler Prins, 1997 Proceedings of XIII ICCP, 1: 187-196] to that of regional substages. Regarding stage names, what little I heard generally supported the idea that the faunal elements characterizing the Russian names for the late Pennsylvanian stages are far more readily recognized throughout most of the large area of Eurasia and the western Arctic region, whereas the faunal elements characterizing the North American names are recognized elsewhere only in part of South America. Possibly a little of the post-Viséan biota characterizing the Russian names is recognized in Angaraland, but the biota of neither set of post-Viséan names is recognized in the Gondwana region. Regarding series subdivision, what I have heard suggests that expanding the Viséan as a series upward to include the Serpukhovian as a stage, and expanding the Westphalian downward to include the upper Namurian [Alekseev, 2001 Carboniferous Newsletter, 19: 14-16], would depart too much from a voluminous amount of traditional literature to be pragmatically useful or acceptable. Thus it appears that the western European terminology for the three higher series of the Carboniferous would most easily be retained for only the regional classification [see Wagner and Winkler Prins, 2002 Carboniferous Newsletter, 20: 14-16]. This proposal also would require three more task groups to be set up to select GSSPs at the base of three Belgian stages, which would be a time-consuming process, considering how long it has taken for the Tournaisian-Viséan boundary to be established. Because no other alternative has been suggested, it appears that the proposal to utilize the positional terms Lower, Middle, and Upper to provide three series in each of the two subsystems [Mississippian and Pennsylvanian] and thus provide six series for the Carboniferous [Heckel, 2001 Carboniferous Newsletter, 19: 12-14] may provide the simplest solution to the issue of establishing Carboniferous Series. This would not require the establishment of any more task groups, and it would not extend established names beyond their generally accepted boundaries in the face of a voluminous literature, because there is little specific literature on the exact boundaries of the Lower, Middle, and Upper Mississippian or the Lower, Middle, and Upper Pennsylvanian. Its most salient flaw, that of not providing much of the expected hierarchy of names because the lower five of the six series would comprise only a single stage, might actually provide its greatest strength, that it could be put in place without the need for any more task groups than are already established and working.

Radiometric Dating

In this issue of the Newsletter, Becq-Giraudon and Bruguier present several new U-Pb zircon dates and a K-Ar illite date from the continental type Stephanian in the French Massif Central. These dates range from 295±5 Ma to 298±5 Ma, and are slightly younger than the Stephanian dates ranging from 298-303 Ma reported in Menning et al. (2000). This would appear to raise the top of the Stephanian higher than shown in my article in last year's Newsletter [20: 10-14], and for this and other reasons, I am updating that article in this Newsletter.

Chemostratigraphy

Saltzman [2003 Geology, 31: 151-154] illustrated a detailed $\delta^{13}C$ curve for the Carboniferous succession at Arrow Canyon, Nevada [where the Mid-Carboniferous boundary GSSP is located], which shows the late Kinderhookian [mid-Tournaisian] enrichment spike that has been documented previously elsewhere. It also shows that the Pennsylvanian section there exhibits broad high-frequency variation ranging from 0 and +1 ‰ on the low end to +3 and +4 ‰ on the high end, which suggests fluctuation that may reflect glacial-interglacial episodes. The maximum values of +4 ‰ are only slightly less than the maximum values of +5 ‰ from the American Midcontinent, but much less than the maximum values of +6 and +7 ‰ from the Russian Platform reported by Mii et al. [2001 Chemical Geology, 175: 133-147]. Some consider this Pennsylvanian divergence of the $\delta^{13}C$ [and to some extent the $\delta^{18}O$] curves between North America and Eurasia to be related to the closure of the marine straits between Gondwana and Euramerica around the time of the Mid-Carboniferous boundary, resulting in the isolation of the Paleotethys and the Panthalassan marine realms from one another. This large-scale interbasin difference of particularly the $\delta^{13}C$ curves between these two tropical regions during the Pennsylvanian diminish the utility of carbon isotope chemostratigraphy for correlating the cold-climate Gondwana and Angara successions with the pan-tropical successions, where the global stage boundaries will be selected. For this reason, the marine strontium isotope [$^{87}Sr/^{86}Sr$] curve that is also derived from carbonates looks more attractive for global correlation of the cold climatic realms with the tropical realms in the Pennsylvanian. Strontium isotope chemostratigraphy was pioneered in the 1970s and 1980s [e. g., Burke et al., 1982 Geology, 10: 516-519], was illustrated for the Upper Paleozoic of North America by Denison et al. [1994 Chemical Geology, 112: 145-167], and has been more recently reviewed by Veizer et al. [1997 Palaeo^3, 132: 65-77; also 1999 Chemical Geology, 161: 59-88]. The $^{87}Sr/^{86}Sr$ curve is shown by Bruckschen et al. [1999 Chemical Geology, 161: 127-163] to have a narrower range with less scatter than the $\delta^{13}C$ and $\delta^{18}O$ curves for the entire Carboniferous, and it shows little difference between the American [Panthalassan] and European [Paleotethyan] data for the Pennsylvanian. More recently, Brand and Brenckle [2001 Palaeo^3, 165: 321-347] and Brand and Bruckschen [2002 Palaeo^3, 184: 177-193] showed the utility of the $^{87}Sr/^{86}Sr$ curve for characterizing and correlating the Mid-Carboniferous boundary between Nevada and the southern Urals. This global signal for the strontium isotope curve results from the facts that the oceans are well mixed with respect to Sr compared to its relatively long residence time in them [~10 myr] and that essentially no mass-dependent Sr isotope fractionation takes place between the ocean water and the carbonates precipitated from it. Therefore, the Sr isotope curve essentially directly reflects long-term global changes in variation of Sr inputs from rivers [with high 87/86 ratios from weathering of crystalline basement and sediments] and from submarine hydrothermal sources [with low 87/86 ratios from the mantle]. That is, it reflects slow-acting global tectonic mechanisms, rather than much shorter-term and generally more local mechanisms [such as organic productivity and oxidation of organic matter] that control the ^{13}C values of marine carbonates and may differ from one ocean to another. I would strongly encourage Carboniferous chemostratigraphers not only to continue to refine the strontium isotope curve for the tropical regions where there is good biostratigraphic control, but also to obtain $^{87}Sr/^{86}Sr$ data from what carbonates are available [particularly brachiopods] in the Angara and Gondwana regions, so that they can be more confidently correlated with the tropical regions.

Philip H. Heckel

SECRETARY / EDITOR'S REPORT 2002-2003

I want to thank all who provided articles for inclusion in Volume 21 of the Newsletter on Carboniferous Stratigraphy and those who assisted in its preparation. I am indebted to P.H. Heckel for editorial contributions; and to P. Thorson Work for coordinating the compilation of this issue

The recent reductions in funding received from ICS combined with a steadily increasing number of corresponding members and a high volume of manuscripts received makes it critical that financial donations from members help offset the resulting increase in publication and mailing costs. The Newsletter is expensive to publish and distribute, and even a modest increase in donations (currently only about 3 % of our membership contributes) would enable us to continue to distribute copies to all who desire them (please refer to the instructions for donations on the last page of this issue).

Future Issues of Newsletter on Carboniferous Stratigraphy

Next year's Volume 22 will be finalized by July 2004, and I request that all manuscripts be sent before May 31—but preferably much earlier. I ask all authors to please read the section below (page 5) regarding submission format, especially manuscript length and diagram scale. Finally, I would be most grateful if all voting and corresponding members of the SCCS would let me know of any changes to their postal and e-mail addresses so that we may update our records.

David M. Work

SCCS ANNUAL REPORT 2002

Membership

The Subcommission had 21 voting members in 2002 [see list at end of Newsletter]. In addition, corresponding membership at the time of publication stands at 294 persons and 7 libraries.

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Task and Exploratory Project Groups

[Note: 'Working Groups' are now called 'Task Groups' by IUGS mandate to ICS]

Task Group to establish a boundary close to the Tournaisian-Viséan Boundary [within the lower part of the Mississippian Subsystem], chaired by George Sevastopulo (Ireland).

Task Group to establish a boundary close to the Viséan-Serpukhovian Boundary [within the upper part of the Mississippian Subsystem], chaired by Barry Richards (Canada), initiated in 2002.

Task Group to establish a boundary close to the Bashkirian-Moscovian Boundary [within the lower part of the Pennsylvanian Subsystem], chaired by John Groves (USA), initiated in 2002.

Task Group to establish a boundary close to the Moscovian-Kasimovian Boundary [above the middle of the Pennsylvanian Subsystem], chaired by Elisa Villa (Spain). This group is also looking at potential boundaries close to the **Kasimovian-Gzhelian Boundary** in the upper part of the Pennsylvanian Subsystem.

Project Group on Comparative Angara and Gondwana Biostratigraphy, chaired by Marina Durante (Russia).

Chief Accomplishments in 2002:

We terminated three of the exploratory project groups and replaced them with two new task groups, one dealing with establishing a boundary close to the Viséan-Serpukhovian boundary, and the other dealing with establishing a boundary close to the Bashkirian-Moscovian boundary. Both of these task groups have established their memberships, and are now compiling information received from their members. The SCCS now has functioning task groups dealing with all the likely stage and series boundaries to be recognized at this time within both subsystems of the Carboniferous.

Work on the Tournaisian-Viséan boundary in the lower part of the Mississippian Subsystem has progressed to the point that its biostratigraphic definition was approved in 2002 by a vote of 19 to 0, with 2 non-responses. Field work is currently underway in southern China that hopefully soon will finalize the choice of the section at which the GSSP will be selected.

Work on the Moscovian-Kasimovian boundary was enhanced by a meeting in Ufa, Russia, where a report on a related group of conodonts that may have wide distribution in the pan-tropical region has led to useful discussions about its relations with the provincial fusulinid successions.

The Newsletter on Carboniferous Stratigraphy, Volume 20, published July 2002, contains reports of Working Groups for 2001, and 12 articles on various topics including: Pennsylvanian radiometric dating in North America and correlation with Europe, correlation of the Viséan-Serpukhovian boundary within Russia and possible boundary markers, microfossil subdivision of the Bashkirian-Moscovian boundary in the southern Urals, biostratigraphy of the Carboniferous of Angaraland, sea-level curve for the lower and middle Desmoinesian (upper Moscovian) in eastern Oklahoma, Pennsylvanian conodont zonation in south China, and several other articles from various parts of the world, for a total of 58 pages.

Work Plan for 2003 and Following Years:

Work in the SCCS is now focused on the XV International Congress on Carboniferous-Permian Stratigraphy, which will be held in Utrecht, The Netherlands in August 2003. There will be a day-long Carboniferous Workshop at which all the task groups dealing with the remaining undefined stage/series boundaries within the system will meet informally to exchange data and ideas, with microscopes available for comparative study of microfossils, along with layout space and projection equipment. There also will be a formal session on paleogeography of the stage boundary intervals and its effects on fossil distribution, at which all the task group chairs will summarize the current status of this knowledge. A meeting of the SCCS is scheduled for the final day of the congress to discuss progress in the boundary task groups and other issues of interest to the SCCS.

We are encouraging further movement toward consensus on competing suggestions for series and stage names and classification within the Mississippian and Pennsylvanian Subsystems, as initiated by the two articles on the subject in the 2001 Newsletter and continued in the 2002 Newsletter.

We are encouraging more work on the radiometric dating of biostratigraphically well constrained successions, and on the chemostratigraphic characterization of the pan-tropical successions in as many ways as possible in order to more accurately correlate the Angara and Gondwana successions with the pan-tropical succession, as outlined in the Chairman's Column.

We are also urging the submittal of the remaining manuscripts for the final volumes of the *Carboniferous of the World* as soon as possible to general editors Robert Wagner and Cor Winkler Prins.

STATEMENT OF OPERATING ACCOUNTS FOR 2001/2002, Prepared by David Work, Secretary (Definitive accounts maintained in US currency)

INCOME (Oct. 31, 2001 – Oct. 31, 2002)	**$US**
IUGS-ICS Grant 2002	$800.00
One-time ICS supplement**	500.00**
2001 SCCS Field Trip (surplus)**	773.42**
Donations from Members	125.00
Interest	1.70
TOTAL INCOME	**$2200.12**
EXPENDITURE	
Newsletter 20 (printing)	$1075.92*
Postage for bulk mailings	526.92
Mailing/Office Supplies	139.71
Bank Charges	199.84
TOTAL EXPENDITURE	**$1942.39**
BALANCE SHEET (2001 – 2002)	
Funds carried forward from 2000–2001	$1892.84
PLUS Income 2001–2002	2200.12
LESS Expenditure 2001–2002	-1942.39
CREDIT balance carried forward to 2003	**$2150.57**

*Specially negotiated rate of <$0.04/page in Cincinnati.

**Special non-recurring sources.

Donations in 2002/2003:

Publication of the Newsletter on Carboniferous Stratigraphy is made possible with generous donations received from members/institutes during 2002-2003 and anonymous donations, combined with an IUGS subsidy of US $900 in 2003, and additional support from a small group of members who provide internal postal charges for the Newsletter within their respective geographic regions.

J. Kullmann, S. G. Lucas, H.W. Pfefferkorn, G. P. Wahlman

COVER ILLUSTRATION

Eoparastaffella morphotypes and morphometric coefficients across the Tournaisian-Viséan boundary.

Illustration: courtesy of F. X. Devuyst and L. Hance (after G. D. Sevastopulo and Tournaisian-Viséan Working Group. 2002. Progress report of the Working Group to establish a boundary close to the existing Tournaisian-Viséan boundary within the Lower Carboniferous. Newsletter on Carboniferous Stratigraphy, v. 20, p. 6, fig. 1).

CONTRIBUTIONS TO THE NEWSLETTER

The Newletter 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 followed by hard copies by regular mail. Manuscripts may also be sent to the address below on diskettes prepared with **Microsoft Word (preferred)** or WordPerfect but any common word processing software or plain ASCII text file can usually be acommodated; printed hard copies should accompany the diskettes. Word processing files should have no personalized fonts or other code. Maps and other illustrations are acceptable in tif, jpeg, eps, or bitmap format (plus a hard copy). 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,

AIR MAIL to: David M. Work
Maine State Museum
83 State House Station,
Augusta, ME 04333, USA

EMAIL to: **david.work@maine.gov**

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

George Sevastopulo

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

Work during the past year has concentrated on completing the description of the proposed GSSP for the base of the Viséan at Pengchong, Guangxi, China and identifying the base of the Viséan in other sections exhibiting different facies in south China. To this end, Professors L. Hance, George Sevastopulo and FX Devuyst, through the good offices of Professor Hou Hong Fei, spent two weeks in South China in November 2002. A manusript proposing the GSSP is in press in Episodes and should be published before the Congress in Utrecht in August.

Progress report from the Task Group to establish a GSSP close to the existing Viséan-Serpukhovian boundary

Barry C. Richards and Task Group

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

Introduction

A SCCS Task Group to establish a Global Stratotype Section and Point (GSSP) as close to the existing Viséan-Serpukhovian boundary as possible was established during the Fall of 2002. The group comprises a membership of 20 scientists representing nine countries and a range of lithostratigraphic, biostratigraphic, chemostratigraphic, and magnitostratigraphic expertise. The membership is tabulated below.

The initial objectives of the task group were to compile preliminary information on: (1) upper Viséan to lowermost Serpukhovian biotic lineages that may prove useful in defining an international lower Serpukhovian boundary; (2) sequence stratigraphic, chemostratigraphic, magnetostratigraphic and other physical stratigraphic events that may prove useful in globally correlating the boundary horizon; (3) the biotic event or events currently used to locate the Viséan-Serpukhovian boundary in sections currently under study by task group members; and (4) the location of stratigraphic sections in which marine strata ‘near’ the boundary are the result of essentially continuous deposition, abundantly fossiliferous, and readily accessible. In order to obtain the preliminary data, a survey was sent to the members. The survey results are summarized below.

NAME	AREA OF EXPERTISE	COUNTRY
Barnett, Andrew Abarnett@badley-ashton.co.uk	Stratigraphy and sedimentology	United Kingdom
Barskov, Igor ibarskov@geol.msu.ru	Conodonts	Russia
Belka, Zdzislaw belka@uni-tuebingen.de	Conodonts	Germany
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Clayton Geoff gclayton@tcd.ie	Palynology	Ireland
Ellwood, Brooks ellwood@geol.lsu.edu	Magnetostratigraphy & magnetosusceptibility	USA
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Kulagina, Elena kulagina@anrb.ru	Foraminifers	Russia
Lane, Richard Hlane@nsf.gov	Conodonts	USA
Luo, Hui huiluo@nigpas.ac.cn	Foraminifers	Peoples Republic of China
Mamet, Bernard Universite de Bruxelles	Foraminifers	Belgium
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Nikolaeva, Svetlana 44svnikol@mtu-net.ru	Ammonoids	Russia
Pazukhin, Vladimir ig@anrb.ru	Conodonts	Russia
Qi, Yu-ping Ypqi@nigpas.ac.cn	Conodonts	Peoples Republic of China
Richards, Barry brichard@nrcan.gc.ca	Stratigraphy and sedimentology	Canada
Riley, Nick njr@bgs.ac.uk	Ammonoids	United Kingdom
Saltzman, Matt Saltzman.11@osu.edu	Chemostratigraphy	USA
Titus, Alan Titus@ut.blm.gov	Ammonoids	USA
Utting, John jutting@nrcan.gc.ca	Palynology	Canada

Lithostratigraphy

The Serpukhovian Stage, proposed by Nikitin (1890), was re-established in the Russian stratigraphic scheme in 1974 by the Interdepartmental Stratigraphic Committee of the USSR and has become internationally recognized (Skompski et al. 1995; Gibshman, 2001). Nikitin (1890) did not designate a stratotype section, but Skompski et al. (1995) stated the Zaborie quarry section, which has been intensively investigated in recent years (Makhilina et al., 1993), could be treated as a lectotype of the Serpukhovian Stage. The type Serpukhovian was deposited in the Moscow Basin and is situated in the Zaborie quarry near the southern margin of the town of Serpukhov, Russia.

The lower boundary of the type Serpukhovian is an unconformity that is traceable throughout much of the Moscow Basin and resulted from a transgression subsequent to latest Viséan regression and subaerial exposure. In the southern part of the basin, this surface caps an uppermost Viséan (Venevian regional horizon) limestone interval containing paleosols. To the southwest, the correlative position lies at the base of a 1-2 m thick unit of variegated sandstone (Skompski et al., 1995).

Limestone predominates in the lower and middle intervals of the Serpukhovian stratotype. The middle part of the section comprises shale, marlstone, and dolostone with limestone interbeds. Like other shallow-marine successions at this stratigraphic level, deposition of the type Serpukhovian was strongly influenced by the major glacial-eustatic changes in sea level that commenced during the late Viséan and continued through the Pennsylvanian. The top of the section is erosional and coincident with the present-day erosion surface.

The type Serpukhovian comprises, in ascending order, the Tarusian, Steshevian, and Protvian horizons (=Russian Platform regional stages). The foraminiferal, ammonoid, and conodont biostratigraphy of the Zaborie section are known through the work of Skompski et al. (1995), Gibshman (2001), and Nikolaeva et al. (2002). The boundary beds in the Zaborie section contain the marker foraminiferal species *Neoarchaediscus postrugosus* and *Janishewskina delicata*. The conodonts *Lochriea cruciformis*, *Lochriea ziegleri,* and *Lochriea senckenbergica* appear near the base of the section (Nikolaeva et al., 2002). The Viséan-Serpukhovian boundary in its type area is approximately correlative with the Viséan-Namurian boundary in the Namur-Dinant Basin of Western Europe (Skompski et al., 1995; Nikolaeva and Kullmann, 2001).

The succession constituting the type Viséan was deposited in the Namur-Dinant Basin of Belgium, northern France, and southern England. There, the type Viséan is represented by a quarry section in Belgium and the contact with the overlying Namurian succession (correlative with the Serpukhovian Stage) is a regional unconformity resulting partly from Variscan tectonism. In Belgium, the magnitude of the latter hiatus is variable, covering at least the upper Warnantian but extending as low as the Livian provincial stage of Belgium. The break generally includes the lowermost Namurian (Pendleian provincial stage) as well (Paproth et al., 1983).

Sequence Stratigraphy

High-resolution sequence stratigraphy has proven to be of considerable utility for detailed correlations in the Upper Viséan and Serpukhovian succession of the Illinois Basin in the United States of America (Smith and Read, 1999) and has the potential to assist with the correlation of a Viséan-Serpukhovian GSSP on an interregional basis.

Biostratigraphy

The preliminary data suggest that the biotic event we use to define the GSSP will be the evolutionary first appearance of a taxon in one of the following groups: conodonts, ammonoids, and foraminifers. Also, it may not be possible to find a suitable global biotic event near the base of the Serpukhovian. Instead, we may need to consider events well down in the upper Viséan, possibly as low as the Asbian provincial stage of the British Isles. The latter position is approximately correlative with the lower Chesterian of North America and the lower Warnantian provincial stage of Belgium

Conodonts

There are three groups of conodont species that could be useful for defining the Viséan-Serpukhovian boundary: a) *Lochriea* species, b) the *Gnathodus bilineatus* group, and c) the *Gnathodus girtyi* group of species.

The most promising and best-documented lineages are within the *Lochrie*a group of species. The *Gnathodus bilineatus* and *G. girtyi* groups of species need additional study. Revision of the *Lochriea* species classification by Nemirovskaya et al. (1994) and verification of their stratigraphic ranges in the most important European localities by Skompski et al. (1995) resulted in the conclusion that a group of the *Lochriea* species ornamented by numerous nodes or ridges appears either at or a short distance below the Viséan-Serpukhovian boundary. Among these species*, L. ziegleri* and *L. cruciformis* occur most commonly and nearest to the boundary (Skompski et al., 1995).

Within the *Lochrie*a group of species, the most important lineages are: 1) *Lochriea nodosa - Lochriea ziegleri* or *Lochriea senckenbergica*, 2) *Lochriea costata - Lochriea cruciformis*, and 3) in the Pyrenees and Cantabrian Mountains of Spain it could also be *Lochriea nodosa - Lochriea multinodosa.*

Ammonoids

It is difficult to find an ammonoid index species that occurs in Western Europe, North America, the Urals of Russia, Central Asia, and Tethyian successions of southern China.

The appearance of the girtyoceratid ammonoid genus *Edmooroceras* (=*Eumorphoceras*) is not only close to the Viséan-Serpukhovian boundary, but is also a fairly widespread taxon, within the right facies. The appearance of the genus is not a particularly important innovation in ammonoid morphology, but it is an easily recognized event and documented from China to Europe and North America. The systematics of upper Viséan to lower Serpukhovian girtyoceratids requires some revision. Once that is completed, *Edmooroceras* could be a viable candidate for a chronostratigraphic marker.

Edmooroceras is a rare element in assemblages outside of Western Europe. If the samples are large enough, it shows up in North America, although it is always less common than *Girtyoceras* and their descendants the tumulitids. One of the advantages of using *Edmooroceras* is that it can be readily recognized using crushed material; sutures are not needed and the ornament is distinctive.

Traditionally, the ammonoid-based Viséan-Serpukhovian boundary in Europe has been identified by the first appearances of the ammonoid genera *Cravenoceras* and *Eumorphoceras*. The problems associated with the use of these ammonoid genera to correlate the Viséan-Serpukhovian boundary were discussed by Nikolaeva and Kullmann (2001) and Nikolaeva et al. (2002). Skompski et al. (1995) reviewed available data on the ammonoid occurrences in the lowermost Serpukhovian on a global basis and also found problems using species of *Cravenoceras* to correlate the boundary.

Within the British Isles, Germany, the southern Urals, and Central Asia, ammonoids can be used for local correlation of the basal Serpukhovian. The correlation is based on *Eumorphoceras pseudocoronula* in Germany, *Cravenoceras leion* in Britain, the first appearance of *Cravenoceras* and *Dombarites carinatus* in the southern Urals, and *Dombarites* in central Asia. However, interregional correlations between North America, Europe, and Asia remain problematical. Perhaps the problem may be solved by research on the phylogeny of earliest *Cravenoceras* (=*Emstites*) and *Dombarites* (*Lusitanoceras*) and latest *Goniatites* from all the above areas in the search for the phylogenetic transitions to define the levels of the first appearances.

The use of ammonoids to correlate with the base of the type Serpukhovian is difficult because that section contains few ammonoids (mostly *Cravenoceras*), occurring well above the boundary level in the Tarusian and overlying Steshevian horizons (Nikolaeva and Kullmann, 2001).

Foraminifers

It is difficult to locate a foraminiferal lineage that could be used for global correlation at the Viséan-Serpukhovian boundary level. Foraminifers are the most abundant and have the highest species diversity in shallow-marine (intertidal to fair-weather wave base) limestone-dominant successions. Because of the late Viséan and Serpukhovian eustatic events, such successions are disrupted by numerous subaerial unconformities. It is, therefore, necessary to look in somewhat deeper-water deposits.

Foraminifer lineages containing *Neoarchaediscus postrugosus* and "*Millerella*" *tortula* appear to be the best candidates for defining a GSSP near the Viséan-Serpukhovian boundary. "*Millerella*" *tortula* and *N. postrugosus* have wide geographic distributions and can be used to correlate between Russia and North America. The appearance of *Janischewskina delicata* may also be useful for global correlation.

The traditionally accepted lineage containing *Neoarchaediscus postrugosus* includes *Asteroarchaediscus bashkiricus - Neoarchaediscus rugosus - Neoarchaediscus postrugosus - Brenckline rugosa*. Within this lineage, the first and second species first appear in the upper Viséan, whereas the lowest occurrence of the third species, *N. postrugosus,* is at the Viséan-Serpukhovian boundary. The first appearance of *B. rugosa* is in the uppermost Serpukhovian (Gibshman, 2001; Nikolaeva et al., 2002).

Based largely on specimens from the Zaborie quarry, Gibshman (2001) recognized the new lineage *"Endostaffella" asymmetrica - "Millerella" tortula - Millerella pressa.* In that section, *"Endostaffella" asymmetrica* occurs in the upper Viséan Venevian horizon, whereas *"Millerella" tortula* first occurs at the Viséan-Serpukhovian boundary. The third species in the lineage, *M. pressa,* occurs in the mid-Serpukhovian.

The phylogeny of "*Millerella" tortula* is somewhat controversial. In contrast to Gibshman (2001), Brenckle and Groves (1981) proposed that *"M." tortula* evolved from *Endostaffella discoidea* (Girty) and gave rise to "*M." designata* and "*M." advena/cooperi* higher in the Chesterian.

The appearance of *Neoarchaediscus postrugosus* is recorded in the Zaborye quarry section (Gibshman, 2001) and the Verchnaya Kardailovka section, in the southern Urals (Nikolaeva et al., 2001, 2002; Pazukhin et al., 2002) near the Viséan-Serpukhovian boundary. The first appearance of *Janischewskina delicata* is recorded in the Zaborie section and in the Bolshoi Kizil section (southern Urals) from the lowermost deposits of the Serpukhovian (Kulagina and Gibshman, 2002).

In the Mississippi Valley region of the U.S.A. there are three potential upper Viséan and lower Serpukhovian levels containing foraminifers that could potentially be used for global correlation. These are: 1) the appearance of the eosigmoilinids at the base of the Menard Limestone, 2) the appearance of "*Millerella tortula*" within the ?Glen Dean/Vienna limestones, and 3) the appearance of asteroarchaediscins (*Neoarchaediscus* and/or *Asteroarchaediscus*) in the Ste. Genevieve Limestone around St. Louis and Ste. Genevieve, Missouri.

The appearance of the asteroarchaediscins (*Asteroarchaediscus baschkiricus* and *A. rugosus* group) is the lowest of the three levels, occurring in the upper Viséan well below the level of the base of the Serpukhovian. This level is significant in that it occurs close to the position recording the onset of the major glacial-eustatic changes characteristic of the Chesterian (= most of the late Viséan and Serpukhovian) and the Pennsylvanian. The appearance of asteroarchaediscins in Eurasia is in the late Viséan and may be somewhat low for defining the Viséan-Serpukhovian boundary. However, work in Eurasia suggests the boundary cannot be picked consistently using the presently accepted markers because those forams are often either rare or their first occurrences have been placed within the upper Viséan by some workers.

The first appearance of *"Millerella" tortula* is close to the base of the Serpukhovian. In the Midcontinent region of North America, Zeller (1953) described *"M." tortula* from the type Glen Dean Limestone of west-central Kentucky, approximately 200 miles from type Chesterian outcrops in southern Illinois. *"M." tortula* has been recorded from several other localities in the U.S.A. including upper Viséan strata in the upper Battleship Wash Formation in Arrow Canyon, Nevada (Brenckle, 1990).

The highest of the three levels is the appearance of the eosigmoilinids in the lower Menard Limestone. It may not be practical to use the eosigmoilinids for boundary definition because they first appear in the upper part of the Serpukhovian in the Zaborie quarry section.

Basins and Sections for Future Study

Conodonts

Upper Viséan to Serpukhovian conodont lineages are best preserved in relatively deep-water outer-neritic to lower-slope and basin deposits. In such facies, species diversity is commonly high and conodonts abundant in terms of frequency and numbers of specimens.

In Europe, lineages within the *Lochrie*a group of species have been studied in numerous sections including those of the Urals (Zhuravlev and Sobolev, 2000; Kossovaya et al., 2001), Moscow Basin (Nikolaeva et al., 2002), Germany (in the Rheinisches Schiefergebirge) and the Cantabrian Mountains of Spain (Nemirovskaya et al., 1994; Skompski et al., 1995). In addition, one of the task group, Qi Yu-ping, recently recognized the lineage *Lochriea nodosa – Lochriea ziegleri and* other lineages in the *Lochrie*a group of species in the Nashui section near the town of Luodian, Guizhou, southern Peoples Republic of China. The best of these occurrences may be in Germany (Schaelk section in the Rheinisches Schiefergebirge) and Spain (Santa Olaja de la Varga and Triollo sections in the Cantabrian Mountains).

In North America, the best sections for defining a GSSP based on conodont lineages may occur in the mixed carbonate-siliciclastic successions of the Chainman Formation and its correlatives, deposited in Antler Foreland Basin of Nevada and western Utah. The reasons for suggesting the Chainman resemble those given below under potential sections for ammonoid study. In the Canadian Rocky Mountains, the carbonate-dominant western occurrences of the upper Viséan and Serpukhovian Etherington Formation, deposited in a northern continuation of Antler Foreland Basin, could also be potential candidates for conodont study across the boundary. In that region, the Etherington is represented by sections comprising hundreds of meters of well exposed middle-ramp carbonates (neritic to upper slope) widely accessible from nearby roads.

Ammonoids

Upper Viséan to Serpukhovian ammonoids are usually common only in basinal facies deposited near active forelands and are often rare in shallow-marine successions.

The Chainman Formation of west-central Utah contains an outstanding opportunity to use ammonoids to document the position of the Viséan-Serpukhovian boundary. The primary reasons for nominating this region are: 1) presence of virtually continuous deeper water successions containing abundant ammonoids associated with conodonts ranging from the Asbian through the upper Pendleian provincial stages; 2) the occurrences are in close proximity to carbonate shelf deposits containing abundant shallow-water taxa that can be correlated fairly unambiguously with the deeper water sections; 3) the sections are situated on Public Lands with good accessibility; and 4) the desert region contains outstanding exposures of the Chainman, including the boundary interval.

Successions in the Urals and Tien Shan probably contain good sections across the Viséan-Serpukhovian boundary, and the extensive ammonoid work completed there provides a good foundation for future study. In the Urals, the best boundary stratotype candidate is the section at Verkhnyaya Kardailovka (southern Urals). This well exposed and accessible section extends from the upper Viséan through the Serpukhovian and comprises relatively deep-water facies containing ammonoids, conodonts, and foraminifers.

Foraminifers

The best candidate sections for defining a GSSP using foraminiferal lineages will probably comprise neritic limestone deposited below fair-weather wave base. In such a setting the potential for subaerial exposure during eustatic drops would have been relatively low yet foraminifers could be moderately abundant.

Good candidate sections for the location of a GSSP defined by foraminifers occur in the Urals. The best of the southern Ural sections may be at the Bolshoi Kizil River (tributary of the Ural River) (Kulagina and Gibshman, 2002; Kulagina et al., 2002). It is located in the Magnitogorsk Zone (eastern Urals) and is dominated by algal bioherm facies. The section at Verkhnyaya Kardailovka in the southern Urals, mentioned above, is another candidate section.

Most sections in the Illinois-Appalachian basins of the Mississippi Valley region, eastern part of Antler Foreland Basin in the western U.S.A. and eastern occurrences of the Etherington Formation in the Canadian Rocky Mountains appear to be unsuitable as foraminifer-based GSSP candidates. Most of these sections contain numerous subaerial disconformities of uncertain chronostratigraphic significance (Smith and Read, 1999). Exceptions probably occur in the deeper water, mixed carbonate-siliciclastic successions in the Chainman Formation of Antler Foreland Basin and western occurrences of the Etherington.

Meetings

The first official meeting of the task group will take place on Wednesday August 13th, 2003 at the Carboniferous workshop in Utrecht, The Netherlands in conjunction with the XV International Congress on the Carboniferous and Permian. The focus of the meeting will be to discuss the information presented in the replies to the surveys sent to task group participants during the latter part of 2002 and early 2003. This will help us to make specific research plans.

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

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The "Task Group to establish a GSSP close to the existing Bashkirian-Moscovian Boundary" was formed in mid-2002 with an initial membership of 18 specialists representing 12 countries and an impressive range of stratigraphic, biostratigraphic and chemostratigraphic expertise. Sadly, our colleague O. P. Fissunenko (Ukraine) passed away earlier this year, leaving the current membership at 17, as follows:

Alekseev, Alexander (Russia)
Altiner, Demir (Turkey)
Brand, Uwe (Canada)
Dzhenchuraeva, Alexandra (Kyrgyzstan)
Fohrer, Beate (Germany)
Groves, John (USA)
Kulagina, Elena (Russia)
Lambert, Lance (USA)
Nemyrovska, Tamara (Ukraine)
Nikolaeva, Svetlana (Russia)
Pazukhin, Vladimir (Russia)
Poletaev, Vladislav (Ukraine)
Samankassou, Elias (Switzerland)
Turner, Nick (England)
Ueno, Katsumi (Japan)
Villa, Elisa (Spain)
Wang Xiangdong (China)

The initial objective of the Task Group was to compile preliminary information on: 1) biotic lineages that may prove useful in defining an international lower Moscovian boundary; 2) chemostratigraphic and other physical stratigraphic events that may prove useful in globally correlating a boundary horizon; and 3) basins (or even individual stratigraphic sections) in which Bashkirian-Moscovian boundary strata are fossiliferous and depositionally continuous or nearly so.

The type area of the Moscovian Stage is in the Moscow Basin where in most places an unconformity separates Moscovian from underlying strata, and where in most places uppermost Bashkirian strata do not contain marine biotas. Accordingly, the search for a lower Moscovian GSSP must extend away from the traditional reference area. Richly fossiliferous and possibly complete successions across the Bashkirian-Moscovian transition are known in the Cantabrian Mountains (Spain), the Donets Basin (Ukraine), the South Urals (Russia), the Taurides (Turkey), south Tien-Shan (Kyrgyzstan), and South China. Of these areas, the Donets Basin and the South Urals have received the most study.

Conodonts and fusulinid foraminifers are the two most widely utilized biotic groups for subdividing and correlating Bashkirian and Moscovian strata. Two conodont lineages that are particularly promising for defining a lower Moscovian boundary, and which warrant further evaluation, are the *Declinognathodus marginodosus—D. donetzianus* lineage and the *Idiognathoides sulcatus—I. postsulcatus* lineage. Among fusulinids, lineages within *Profusulinella*, from *Profusulinella* to *Aljutovella*, from *Pseudostaffella* to *Neostaffella*, and from *Verella* to *Eofusulina* are important in the Bashkirian-Moscovian boundary interval. It is clear, however, that fusulinids were more provincial than conodonts, and this somewhat diminishes their usefulness in intercontinental biostratigraphy.

Carbon and oxygen isotope shifts, while stratigraphically useful regionally, probably are not useful as global seawater proxies during the Bashkirian-Moscovian transition because of oceanographic separation of the Panthalassian and Paleotethyan realms, leading to the possibility that local oceanographic conditions overprinted global isotopic trends. Strontium isotope trends, in contrast, do not suffer from this limitation and therefore offer considerable global correlation potential once calibrated against biostratigraphic events in key lineages.

The first official meeting of the Task Group will occur in Utrecht in conjunction with the XV ICCP. This meeting will enable us to identify specific research plans for meeting the 2008 deadline for selecting a GSSP.

Progress report of the Task Group to establish a GSSP close to the Moscovian-Kasimovian boundary

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The Task Group on a GSSP close to the Moscovian-Kasimovian boundary has continued studies on several potential levels of correlation within the interval from the uppermost Moscovian (upper Desmoinesian) to the lower Gzhelian (lower Virgilian) in the Pennsylvanian Subsystem. Main lines of investigation were summarized in the 2002 issue of Carboniferous Newsletter (Villa and Working Group, 2002). Recent updates follow:

Studies

Fusulinoidean faunas show strong provincialism during the interval analyzed, hampering their use for long distance correlation. However, some episodes of faunal dispersal might exist. Two remarkable events are: 1) the appearance of the Eurasian genus *Protriticites* in western USA (Wahlman and others, 1997; Wahlman, 1999) in mid-upper Desmoinesian strata, and 2) the wider distribution in Eurasia of *Rauserites rossicus* (Villa and others, 2003) at beds considered to belong to the lower Gzhelian.

Conodont faunas are being intensively investigated in several relevant areas, with new data from the North American Midcontinent, Paradox Basin, the Cantabrian Zone, Moscow Basin, Donets Basin, and South Urals. (Some of this information has been already published by Barrick and others, 2002, Lambert and others, 2002, Ritter and others, 2002). The paper by Ritter and others (2002), apart from showing the detailed conodont content of the Honaker Trail section (Paradox Basin, Utah), documents the occurrence in this basin of the fusulinoidean *Protriticite*s as approximately equivalent to the Lower Pawnee cyclothem of the Midcontinent, the third major cyclothem [but sixth marine unit] below the base of the Missourian Stage. This is also below the first appearance of the new genus *Swadelina* Lambert, Heckel and Barrick, 2003, which Lambert and others (2001) used [as new genus S] to name the highest idiognathodontid conodont zone of the Desmoinesian.

Other relevant conodont information concerns the Las Llacerias section in the Cantabrian Mountains. Carlos Méndez reports a significant finding of *Gondolella pohli*, which suggests correlation of part of the upper Myachkovian of Eurasia with the late middle Desmoinesian Verdigris cyclothem of North America. Higher in this section, an isolated specimen of *Idiognathodus eccentricus* in the upper part of the *Protriticites* Zone suggests the correlation of a level within the upper Kreviakinian with the lower Missourian (Méndez, 2002).

Aleksander Alekseev (Moscow State University) reported finding *Idiognathodus fischeri* sp. nov. in limestone N3/2 of the Kalinovo section in the Donets Basin, suggesting the correlation of this level with the upper part of the Suvorovo Formation (lowermost Kasimovian) of the Moscow Basin. Alekseev and his group also investigated the distribution of fusulinoideans and conodonts in the Dalniy Tyulkas succession in the South Urals [Bashkiria, Russia], and correlated this section with the Moscow Basin succession, based on occurrence of *Streptognathodus makhlinae*, a taxon characteristic of upper Krevyakinian strata in the Moscow Basin, overlain by strata containing *Idiognathodus sagittalis*, a form occurring in the Khamovnikian Neverovo Formation of the Moscow Basin, which also has been recognized in the Donets Basin, Spain, and American Midcontinent. New advances on stratigraphy, paleontology of several fossil groups, biozonation, and correlation of the South Urals successions are compiled in Alekseev and others, 2002.

2002 Field Trip and Meeting

During August 2002, the Task Group held a meeting in Ufa, Bashkiria, where A. Alekseev and colleagues, N.V. Goreva, E.I. Kulagina, O.L. Kossovaya, and A.N. Reimers, led a field trip to the Dalniy Tyulkas sections in the South Urals, to begin evaluation of their potential as a candidate for a GSSP for the Moscovian-Kasimovian boundary. Besides the organizers, the following task group members attended this field trip: P.Heckel, L. Lambert, W. Buggisch, B. Fohrer, E. Samakassou, V. Davydov, and S. Remizova.

The poorly exposed critical portion has been recently trenched and sampled in the Dalniy Tyulkas sections by the Moscow group. Preliminary results show a possible transition from Moscovian to Kasimovian conodonts involving *I. sagittalis*. Werner Buggisch of the University of Erlangen collected closely spaced samples for stable C and O isotope analysis, and recent Moscow State University Ph.D. graduate Pavel Kabanov has started a detailed study of the sedimentary petrology and sequence stratigraphy of this succession in order to provide a complete analysis of the depositional environments.

At the meeting in Ufa, Alekseev indicated that the conodont lineage that includes *I. sagittalis* now appears to hold more promise for providing a correlatable evolutionary event upon which a GSSP might be based, than do previously considered older lineages. An event in the *I. sagittalis* lineage would be slightly younger than the traditional base of the Kasimovian around Moscow, and would be closer to the Desmoinesian-Missourian regional boundary established in North America (Heckel and others, 2002), which is based on the first appearance of *I. eccentricus*, a taxon that is related to the *I. sagittalis* lineage. Fusulinid worker V. Davydov expressed a desire to retain the traditional Moscovian-Kasimovian boundary and define it on an evolutionary event in a fusulinid lineage that could correspond to the lineage leading from primitive to advanced *Protriticites*. Fusulinid worker S. Remizova expressed support for a younger boundary near the first appearance of the fusulinid *Montiparus*, because that genus is more easily recognized than those around the traditional base of the Kasimovian. This younger fusulinid boundary would be closer to a boundary established in the *I. sagittalis* conodont lineage.

Although it appears promising that an event in the *I. sagittalis* lineage might be identified to define the Moscovian-Kasimovian boundary, the taxonomy of this apparently widespread group of morphotypes that includes *I. sagitallis*, *I. eccentricus*, its ancestor *I. sulciferus*, and their relatives must be worked out among the European and American workers. As this report is being written [late May], conodont experts A. Alekseev, J. Barrick, N. Goreva, and T. Nemyrovska are meeting in Moscow in order to work on the taxonomy of the morphotypes, and perhaps to delineate an event that can be identified in Russia, the Ukraine, the U.S., and other parts of the world where marine rocks exist across this boundary.

The next Task Group meeting will be held in Utrecht, Netherlands, during the coming International Congress on Carboniferous and Permian Stratigraphy in August, 2003.

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CONTRIBUTIONS BY MEMBERS

Updated cyclothem constraints on radiometric dating of the Pennsylvanian succession in North America and its correlation with dates from Europe

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Since my previous article on this subject (Heckel, 2002a), I have more rigorously tabulated the cyclothem data and groupings upon which I based my estimates of cycle periods and evaluations of the radiometric dates that are available for the Pennsylvanian succession in North America. I also had the opportunity to interact with other Carboniferous stratigraphers at an April 2003 meeting on global correlation organized by Manfred Menning at the Geoforschungszentrum in Potsdam, Germany. As a result of these activities and some more recent literature, I felt that it was appropriate to update and modify my assessment of the ages of stage and other boundaries of the Carboniferous, based on the available radiometric dates calibrated by the constraints of probable ranges of cyclothem periods.

North American Radiometric Dates

In contrast to the many dates derived from volcanic tuffs and tonsteins listed from central and western Europe by Menning et al. (2000), the one currently known date obtained from a similar rock type in North America is that of Kunk and Rice (1994) from the Fire Clay tonstein in the Appalachian Basin. This date of 310.9±0.8 [essentially 311±1] Ma lies halfway between the Kendrick and Magoffin marine members of the Breathitt Formation. It is correlated with the upper part of the Trace Creek Member in the lower Atoka Formation of the southern Midcontinent based on ammonoid zonation (Rice et al. 1994) and with beds near the Westphalian B-C [Duckmantian-Bolsovian] boundary in western Europe based on plant fossils. This date is derived from sanidine using the Ar/Ar plateau method and thus is considered a maximum age [Scale B] by Menning et al. (2000, figure 6), the scale that they suggest (p. 10) should normally be used. This date agrees closely with dates of ~310-311 Ma [with wider error ranges] around the Westphalian B-C boundary in Germany shown by Menning et al. (2000, figure 6), which are also derived from sanidines using the Ar/Ar plateau method, but include one U-Pb zircon date. This not only provides a radiometric tie point for the late early Atokan Stage, but also supports the approximate correlation of the Atokan with Westphalian B and C [Duckmantian and Bolsovian] based on various groups of fossils.

Using a U-Pb method of dating certain penecontemporaneous paleosol calcites [caliche], which are common between marine units in the cyclic non-volcanic North American Pennsylvanian succession, Rasbury et al. (1998) estimated the Carboniferous-Permian boundary at 301±2 Ma and the Missourian-Virgilian boundary at 307±3 Ma in the southwestern U.S. However, more recent unpublished conodont data suggest that this succession is not as well biostratigraphically constrained as originally thought in this tectonically disturbed area. Using the same method in the same laboratory, Becker et al. (2001) reported dates for biostratigraphically well constrained named units in the relatively undisturbed western part of the Appalachian Basin. They dated the paleosol directly below the lower Virgilian Ames Limestone at 294±6 Ma, and the late Desmoinesian lacustrine Upper Freeport Limestone at 302±4 Ma. As evaluated below, the Appalachian dates are more consistent with the 311-Ma late early Atokan volcanic sanidine date lower in the Appalachian succession because they provide a span of 9 million years for the middle and upper Atokan and nearly the entire Desmoinesian stages, rather than the much shorter 4 million years for the same amount of Atokan, plus the entire Desmoinesian and Missourian stages provided by the southwestern Missourian-Virgilian boundary date of 307±3 Ma.

Cyclothem Estimates of Stage Duration

Menning et al. (2000) used stratal thickness estimates to help evaluate the many disparate radiometric dates and calibrate the dated succession in western Europe. Using stratal thickness to estimate time is fraught with uncertainty because of the greatly variable rates of sedimentation and of tectonic subsidence that provided accommodation space. However, shelf successions of glacially induced cyclothems of a constrained range of periods, which are also able to be biostratigraphically correlated by evolving conodont lineages, provide the most likely setting for relatively more accurate estimates to be obtained by this method. Therefore, I use numbers of recognized transgressive-regressive cyclothems in Midcontinent North America, in various groupings as to scale, to estimate relative durations of stages in that region. Recognizing the lack of precision in the cyclothem data, and also in the radiometric dates with wide error ranges, I offer the following updated age estimates of important boundaries in the Midcontinent Pennsylvanian based only on the dates that are biostratigraphically well constrained.

The lower Virgilian sub-Ames Limestone date of 294±6 Ma and the late Desmoinesian Upper Freeport Limestone date of 302±4 Ma provide a span of about 8 m.y. for the highest Desmoinesian, lowest Virgilian and the entire intervening Missourian Stage. Considering that the Altamont cyclothem is the probable Midcontinent correlative of the Upper Freeport Limestone and the Oread cyclothem is the known Midcontinent equivalent of the Ames Limestone (Heckel, 1994), this span encompasses at least 32 cyclothems of all scales (Fig. 1A, B), which provides an average maximum cycle period of 250 k.y. (Fig. 2). Because this period is halfway between the 100-k.y. and 400-k.y. periods of the two longer orbital parameters involved in glacial eustasy, it implies that cyclothems of the largest scales [major and intermediate of Heckel (1986)] are more strongly controlled by the longest period and those of minor scale are more controlled by the shorter periods of the orbital parameters. Therefore, the minor cycles are grouped with those of larger scale to attempt to delineate probable 400-k.y. cyclothems. Within this same Altamont to Toronto [sub-Oread] succession, there are 17 major and intermediate-scale cyclothems, which provide an estimate of about 470 k.y. for the period of this scale of cyclothem [grouped to include adjacent minor cyclothems], not far above the 400 k.y. expected for the longest orbital parameter. Considering the wide error ranges on these two younger Appalachian dates, I assumed an average 400-kyr period for the major to intermediate cyclothems in this succession. Each cycle of larger scale was then grouped with any adjacent minor cyclothems, and in 3 cases, intermediate cycles were grouped with intermediate or major cycles to which they seem related. The verbal description of these groupings and computations used in last year's article are replaced here with charts showing all the cycle groupings from basal Desmoinesian through the top of the Virgilian as they were grouped last year (Fig. 1A), in order to show the basic data for the 2002 cyclothem-period calculations based on the Appalachian dates, and the cyclothem estimates of North American stage durations based on the assumptions used then. This set of assumptions applied to this grouping yielded 20 Desmoinesian 400-k.y. cycles, 10 Missourian 400-k.y. cycles, and 15 Virgilian 400-k.y. cycles, with the estimated Atokan-Desmoinesian boundary at 308 Ma, Desmoinesian-Missourian boundary at 300 Ma, Missourian-Virgilian boundary at 296 Ma and the Virgilian [Carboniferous]-Permian boundary at 290 Ma, where Harland et al. (1990) had estimated it. These calculated cyclothem-period estimates were based on the means of the Appalachian dates and deviated only 67 to 171 k.y. from the assumed 400-kyr period of the cyclothems (Fig. 2A).

More recently, from discussions with several geologists [including M. Menning, V. Davydov, B. Chuvashov, and H. Forke] in the April 2003 meeting at the Geoforschungszentrum in Potsdam, new data suggest that the date of the Carboniferous-Permian boundary may be somewhat older than the 290-Ma estimate given above. Also, recent detailed sequence-stratigraphic work on the late Virgilian succession in Kansas by Olszewski and Patzkowski (2003) groups the minor [their 'meter-scale'] cycles [similar in scale to most of those recognized by Boardman (1999)] into fewer groupings than I had. Their groupings [termed 'composite sequences'] are bounded by more significant disconformities than the minor cycles, and they regard them as '4th order cycles' that are equivalent in temporal duration [period] to the major [Kansas-type] cyclothems that I described from the Missourian. In addition, Nadon and Kelly (in press) describe several minor cycles of sea-level fluctuation within a marine unit [Portersville] in the Appalachian Basin, which Heckel (1994) recognized as equivalent to a single major cyclothem [Iola] in the midcontinent. These minor cycles appear to be the nearshore manifestation of the shorter orbital parameters that are essentially masked offshore by greater water depth where small fluctuations cause no identifiable depth-related facies changes in the midcontinent, where this cyclothem was counted as only one cycle. These latter two points suggest that many more minor cycles in nearer-shore positions are equivalent to the major cyclothems that contain widespread deep-water facies, than I had estimated previously. Therefore, it is appropriate to regroup the cyclothems, particularly the successions of many minor cycles in the lower Desmoinesian and upper Virgilian that may represent more nearshore manifestations of larger grouping units, into fewer 400-k.y. groupings (Fig. 1B), recalculate the apparent major cycle grouping periods (Fig. 2B), and recalculate the ages of the stage boundaries to reflect the resulting shorter stage durations, and ultimately recalibrate the more likely position of the younger Appalachian dates away from their means but within their error ranges (Fig. 3). The newer, fewer groupings reduce the duration of the Desmoinesian from 8 to 5 m.y., the duration of the Missourian from 4 to 3 m.y., and the duration of the Virgilian from 6 to 4 m.y. (Fig. 4). Retaining the 3-m.y. estimate for the duration of the middle and late Atokan time span above the Appalachian tonstein date of 311 Ma (Heckel, 2002a), this moves the Desmoinesian-Missourian boundary from 300 to 303 Ma, the Missourian-Virgilian boundary from 296 to 300 Ma, and the Virgilian [Carboniferous]-Permian boundary from 290 to 296 Ma (Fig. 4). Note that these new estimates are still compatible with the error ranges of the younger Appalachian dates in that the new cyclothem calibration for the Upper Freeport Limestone is 303.4 Ma, within the error range of 298-306 Ma for its computed date of 303±4 Ma, and the new cyclothem calibration for the sub-Ames paleosols is 299.4 Ma, just within its error range of 288-300 Ma for its computed age of 294±6 Ma (Fig. 3). Note also that this recomputed Carboniferous-Permian boundary date of ~296 Ma is the same as that being used by Menning's Geoforschungszentrum group as a compromise between the younger and older dates [~292-~300 Ma] that have been proposed by various authors.

Reevaluation of Southwestern U.S. Dates

Assuming equal durations, recognition of all cycles, and no sys-

2002 CHART OF MIDCONTINENT PENNSYLVANIAN CYCLOTHEMS, GROUPINGS, AND AGE DATES

NA Stg.	Cyclothems of all scales	Cyclothem Grouping	Date [Ma]
Vg	Mid-Johnson Long Creek **UPPER HUGHES CK** **Middle Hughes Creek**	**HUGHES CK**	301±2 [R]
	Lower Hughes Creek **Americus** Basal Americus Upper Hamlin	**Americus**	
	Lower Hamlin **Five Point** West Branch **Falls City**	**Falls City- Five Point**	
	Aspinwall **Brownville** Grayhorse	**Brownville**	
	Nebraska City French Creek Jim Creek **Grandhaven**	**Grandhaven**	
	Dover-Dry Maple Hill Wamego Tarkio	**Dover-Dry**	
	Elmont **Reading**	**Reading- Elmont**	
	Wakarusa **Burlingame**	**Burlingame- Wakarusa**	
	Silver Lake **Rulo** Happy Hollow White Cloud	**Rulo**	
	Winzeler **HOWARD [Shn Ck/Aarde]**	**HOWARD**	
	Bachelor Creek **TOPEKA [Holt]** Sheldon	**TOPEKA**	
	Curzon **Hartford** **DEER CK [Larsh-Burroak]** Ozawkie	**DEER CK**	
	Ost **Avoca** **LECOMPTON [Qn Hill]** **Spring Branch**	**LECOMPTON**	
	Clay Creek Kereford **OREAD [Heebner]** **Toronto**	**OREAD**	**[B] 294±6**
Vg	Amazonia **CASS [Little Pawnee]**	**CASS**	
Mo	Westphalia **Iatan** **South Bend [Gretna]**	**South Bend- Iatan**	307±3 [R]
	STANTON [Eudora]	**STANTON**	
	Plattsburg [Hickory Ck] Upper Farley Lower Farley **Wyandotte [Quindaro]**	**Wyandotte- Plattsburg**	
	IOLA [Muncie Creek] Mid-Chanute	**IOLA**	

	DEWEY [Quivira]	**DEWEY**	
	Drum-Westerville **Cherryvale [Block-Wea]** Hogshooter-upr Winterset	**Cherryvale**	
	mid-Winterset [2 cycles] **DENNIS [Stark]**	**DENNIS**	
	Mound Valley **SWOPE [Hushpuckney]**	**SWOPE**	
	Sniabar **HERTHA [Mound City]**	**HERTHA**	
Mo Ds	Critzer **Exline** Checkerboard-S. Mound	**Exline**	
	Glenpool **LOST BR'CH [Nuyaka Ck]**	**LOST BRANCH**	
	Idenbro **Norfleet**	**Lenapah- Norfleet**	
	ALTAMONT [Lk. Neosho] Amoret **Farlington**	**ALTAMONT**	**302±4 [B]**
	Coal City [Joe] **LOWER PAWNEE [Anna]** Wimer School-Sageeyah	**PAWNEE**	
	Higginsville **UP FT SCOTT [Lit. Osage]**	**UPPER FT SCOTT**	
	Upper Blackjack Creek **LWR FT SCOTT [Excello]**	**LOWER FT SCOTT**	
	Breezy Hill **Post-Bevier**	**Bevier**	
	Upper Ardmore **VERDIGRIS [Oakley]**	**VERDIGRIS**	
	Post-Fleming **Post-Mineral/Russell Ck**	**Min./Russell Ck-Fleming**	
	UPPER TIAWAH **POST-TEBO/LR TIAWAH**	**TIAWAH**	
	Post-RC Coal **POST-WEIR-PITTSBURG**	**WEIR- PITTSBURG**	
	Uppermost Boggy **Post-Wainwright**	**Wainwright**	
	INOLA	**INOLA**	
	Post-Peters Chapel Post-Secor Rider Post-Secor Post-Lower Witteville	Secor- Peters Chapel	
	POST-DRYWOOD	**DRYWOOD**	
	POST-ROWE-DONELEY	**DONELEY**	
	Sam Creek Post-Tullahassee Spaniard	**Sam Creek**	
	Post-Keota Post-Tamaha Post-Stigler Post-Warner	Tamaha grouping	
	Post-Keefeton **UPPER McCURTAIN**	**UPPER McCURTAIN**	
Ds	**LOWER McCURTAIN**	**LOWER McCURTAIN**	
At	Upper [cycles not delin't'd]		
	Middle [" " "]		
At	Lower [" " "]		**311±1 [KR]**

Figure 1A. – Chart showing estimated 400-k.y. cyclothem groupings used in Heckel (2002a), based on periods of time between means of Appalachian radiometric dates. Information for lower Desmoinesian succession is from Boardman et al. (2002), for upper Desmoinesian, Missourian and lower Virgilian succession from Heckel (1994, 2002b), and for upper Virgilian succession from Boardman (1999). Symbols: At=Atokan, Ds=Desmoinesian, Mo=Missourian, Vg=Virgilian; **MAJOR CYCLOTHEM [core shale]; Intermediate cyclothem;** Minor cyclothem. **Appalachian dates: [B]=Becker et al. (2001), [KR]=Kunk and Rice (1994);** Southwestern U.S. dates: [R]=Rasbury et al. (1998).

2003 CHART OF MIDCONTINENT PENNSYLVANIAN CYCLOTHEMS, GROUPINGS, AND AGE DATES

NA Stg	Cyclothems of all scales	Cyclothem Grouping	Date [Ma]
Vg	Mid-Johnson Long Creek **UPPER HUGHES CK** **Middle Hughes Ck** Lower Hughes Ck **Americus** Basal Americus	**FORAKER** [formation name] **[III of O&P 2003, with 12 cycles]**	301±2 [R]
	Upper Hamlin Lower Hamlin **Five Point** West Branch **Falls City**	**Admire** [gp name] **[=Falls City-Five Point, 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 [Shn Ck/Aarde]**	**HOWARD**	
	Bachelor Creek **TOPEKA [Holt]** Sheldon	**TOPEKA**	
	Curzon **Hartford** **DEER CK [Larsh-Burroak]** Ozawkie	**DEER CREEK**	
	Ost **Avoca** **LECOMPTON [Qn Hill]** **Spring Branch**	**LECOMPTON**	
	Clay Creek Kereford **OREAD [Heebner]** **Toronto**	**OREAD**	**[B]** **294±6**
Vg **Mo**	Amazonia **CASS [Little Pawnee]** Westphalia	**CASS**	
	Iatan **South Bend [Gretna]** **STANTON [Eudora]** **Plattsburg [Hickory Ck.]**	**STANTON**	307±3 [R]
	Upper Farley Lower Farley **Wyandotte [Quindaro]** **IOLA [Muncie Creek]** Mid-Chanute	**IOLA**	

	DEWEY [Quivira]	**DEWEY**	
	Drum-Westerville **Cherryvale [Block-Wea]** Hogshooter-upr Winterset	**Cherryvale**	
	mid-Winterset [2 cycles] **DENNIS [Stark]**	**DENNIS**	
	Mound Valley **SWOPE [Hushpuckney]**	**SWOPE**	
Mo **Ds**	Sniabar **HERTHA [Mound City]** Critzer **Exline** Checkerboard-S. Mound	**Exline-HERTHA**	
	Glenpool **LOST BR'CH [Nuyaka Ck]**	**LOST BRANCH**	
	Idenbro **Norfleet** **ALTAMONT [Lk. Neosho]** Amoret **Farlington**	**ALTAMONT**	**302±4** **[B]**
	Coal City [Joe] **LOWER PAWNEE [Anna]** Wimer School-Sageeyah	**PAWNEE**	
	Higginsville **UP FT SCOTT [Lit. Osage]**	**UPPER FORT SCOTT**	
	Upper Blackjack Creek **LWR FT SCOTT [Excello]** Breezy Hill	**LOWER FORT SCOTT**	
	Post-Bevier Upper Ardmore **VERDIGRIS [Oakley]**	**VERDIGRIS**	
	Post-Fleming **Post-Mineral/Russell Ck** **UPPER TIAWAH** **POST-TEBO/LR TIAWAH**	**TIAWAH**	
	Post-RC Coal **POST-WEIR-PITTSBURG** Uppermost Boggy Post-Wainwright	**WEIR-PITTSBURG**	
	INOLA Post-Peters Chapel Post-Secor Rider Post-Secor Post-Lower Witteville	**INOLA**	
	POST-DRYWOOD **POST-ROWE-DONELEY**	**DONELEY-DRYWOOD**	
	Sam Creek Post-Tullahassee Spaniard Post-Keota Post-Tamaha Post-Stigler Post-Warner	Tamaha- **Sam Creek** grouping	
	Post-Keefeton **UPPER McCURTAIN**	**UPPER McCURTAIN**	
Ds	**LOWER McCURTAIN**	**LOWER McCURTAIN**	
At	Upper [cycles not delin't'd]		
	Middle [" " "]		
At	Lower [" " "]		**311±1** **[KR]**

Figure 1B. – Chart showing estimated 400-k.y. cyclothem groupings, utilizing fewer groupings because of newer information from Olszewski and Patzkowski (2003), personal communication from V. Davydov (2003) on probability of older dates for Carboniferous-Permian boundary, and other stratigraphic information. Regrouping of lower Desmoinesian succession received input from T. R. Marshall and D. R. Boardman. Upper Virgilian may be better grouped to include one more major grouping extending from White Cloud through Wakarusa cycle according to D.R. Boardman (personal communication, 2003). Symbols: At=Atokan, Ds=Desmoinesian, Mo=Missourian, Vg=Virgilian; **MAJOR CYCLOTHEM [core shale]; Intermediate cyclothem;** Minor cyclothem. **Appalachian dates: [B]=Becker et al. (2001), [KR]=Kunk and Rice (1994);** Southwestern U.S. dates: [R]=Rasbury et al. (1998).

A. 2002 CYCLOTHEM PERIODS CALCULATED FROM APPALACHIAN MEAN DATES, USING MORE GROUPINGS

All Appalachian dates	Date/ Duration	# of all cycles	# of all cycles per m.y.	Average cycle period	# of major cycle groupings	# of major cycle gpgs. per m.y.	Average cycle grouping period
Sub-Ames paleosol [early Virgilian, sub-Oread]	**294±6**						
Interval includes entire Missourian	**~8 m.y.**	**32**	**4**	**250 k.y.**	**14**	**1.75**	**571 k.y.**
Upper Freeport Limestone [late Desmoinesian, Altamont]	**302±4**						
Interval includes mid and late Atokan and most of Desmoinesian	**~9 m.y.** [est. **6***~ Desm.]	**38 Desm.**	**6.3**	**158 k.y.**	**18 Desm.**	**3.0**	**333 k.y.**
Fire Clay tonstein [late early Atokan]	**311±1**						

B. 2003 CYCLOTHEM PERIODS CALCULATED FROM APPALACHIAN MEAN DATES, USING FEWER GROUPINGS

All Appalachian dates	Date/ Duration	# of all cycles	# of all cycles per m.y.	Average cycle period	# of major cycle groupings	# of major cycle gpgs. per m.y.	Average cycle grouping period
Sub-Ames paleosols [B] [early Virgilian, sub-Oread]	**294±6**						
Interval includes entire Missourian	**~8 m.y.**	**32**	**4**	**250 k.y.**	**10****	**1.25**	**800 k.y.**
Upr. Freeport Limestone [B] [late Desmoinesian, Altamont]	**302±4**						
Interval includes mid and late Atokan and most of Desmoinesian	**~9 m.y.** [est. **6***~ Desm.]	**38 Desm.**	**6.3**	**158 k.y.**	**11.5*** Desm.**	**1.92**	**522 k.y.**
Fire Clay tonstein [K&R] [late early Atokan]	**311±1**						

* assuming middle and late Atokan time lasted ~3 m.y. [see Heckel, 2002a, p. 11].
** from middle of Altamont to middle of Oread major grouping.
*** from base of Lower McCurtain to middle of Altamont major grouping.

Figure 2. – Cyclothem periods calculated from Appalachian radiometric date means based on two different 400-k.y. cyclothem groupings. A: Original greater number of cyclothem groupings used in 2002, which yielded periods varying from 76 to 171 k.y. less or greater than 400 k.y. B: Newer, fewer cyclothem groupings based on new information [see Figure 1B caption], which yielded periods varying from 122 to 400 k.y. greater than 400 k.y. Appalachian dates: [B]=Becker et al. (2001), [KR]=Kunk and Rice (1994).

2003 CYCLOTHEM CALIBRATION OF APPALACHIAN DATES, UTILIZING FEWER 400-K.Y. MAJOR GROUPINGS

All Appalachian dates	Orig. mean date [w. error range] /Interval duration	# of major cycle groupings	Average major cycle grouping period	# of major cycle groupings per m.y.	Recalibrated Date and Interval Duration
Sub-Ames paleosol [early Virgilian, sub-Oread]	**294±6 Ma [288-300 Ma]**				**299.4** [just within error range]
Interval includes entire Missourian plus base of Virgilian and top of Desm.	**~8 m.y.**	**10**	**<u>400</u> k.y.**	**<u>2.5</u>**	**4.0 m.y.**
Upper Freeport Limestone [late Desmoinesian, Altamont]	**302±4 Ma [298-306 Ma]**				**303.4** [within error range]
Interval includes mid and late Atokan and most of Desmoinesian	**~9 m.y.** [est. **6 m.y.** for Desm.]	**11.5 Desm.**	**<u>400</u> k.y.**	**<u>2.5</u>**	**~4.6 m.y. Desm. <u>plus 3 m.y.-m+u Atokan</u> = 7.6 m.y.**
Fire Clay tonstein [late early Atokan]	**311±1**				

Figure 3. – Cyclothem recalibration of two younger Appalachian dates within their error ranges, based on greater variation away from their means when fewer assumed 400-k.y. grouping of cycles are used (Fig. 2B). Assumptions are underlined.

tematic distribution of missing cycles, Rasbury et al. (1998) estimated an average cycle period of 143±64 k.y. for all cycles in the successions they studied, but they recognized only 29 cycles in the Virgilian, compared to the approximately 50 cycles of all scales recognized by Boardman (1999) in the Midcontinent where the succession is more complete and is overlain by basal Permian strata accurately correlated by conodonts with the definitive Uralian succession. This more complete figure of 50 cycles provides an average cycle period of 120 k.y. for the 6 m.y. length of the Virgilian based on their dates (Figure 5A), which is even closer to the 100-k.y. orbital parameter involved in glacial eustasy. However, applying this average cycle period similarly to the total of 24 cycles of all scales in the Missourian produces a length of 2.9 m.y., and the total of 40 cycles of all scales in the Desmoinesian yields 4.8 m.y. This total of 7.7 m.y. far exceeds the 4 m.y. span between their Missourian-Virgilian boundary mean date of 307 Ma and the Appalachian late early Atokan tonstein sanidine date

A. 2002 CYCLOTHEM ESTIMATES OF NORTH AMERICAN STAGE DURATIONS, USING MORE 400-K.Y. GROUPINGS

Assuming: 400 k.y. cycle grouping period & 300 Ma date for Ds-Mo. bdy	Date/ Duration	# of all cycles	# of all cycles per m.y.	Average cycle period	# of major cycle groupings	# of major cycle gpgs. per m.y.	Average cycle grouping period
Carboniferous-Permian Boundary as correlated	290 Ma						
Entire Virgilian Stage	~6 m.y.	50	8.3	120 k.y.	15	2.5	400 k.y.
Missourian-Virgilian Boundary	296 Ma						
Entire Missourian Stage	~4 m.y.	23	5.75	174 k.y.	10	2.5	400 k.y.
Desmoinesian-Missourian Bdy	300 Ma						
Entire Desmoinesian Stage	~8 m.y.	44	5.5	182 k.y.	20	2.5	400 k.y.
Atokan-Desmoinesian Bdy	308 Ma						
Mid and late Atokan Stage	~3 m.y.						
Fire Clay tonstein [late early Atokan]	311 Ma						

B. 2003 CYCLOTHEM ESTIMATES OF NORTH AMERICAN STAGE DURATIONS, USING FEWER 400-K.Y. GROUPINGS

Assuming: 400 k.y. cycle grouping period &~3 m.y. durat'n for M-L Atok'n	Date/ Duration	# of all cycles	# of all cycles per m.y.	Average cycle period	# of major cycle groupings	# of major cycle gpgs. per m.y.	Average cycle grouping period
Carboniferous-Permian Boundary as correlated	296 Ma						
Entire Virgilian Stage	~4 m.y.	50	12.5	80 k.y.	10	2.5	400 k.y.
Missourian-Virgilian Boundary	300 Ma						
Entire Missourian Stage	~3 m.y.	23	7.7	130 k.y.	7	2.5	400 k.y.
Desmoinesian-Missourian Bdy	303 Ma						
Entire Desmoinesian Stage	~5 m.y.	44	8.8	114 k.y.	13	2.5	400 k.y.
Atokan-Desmoinesian Bdy	308 Ma						
Mid and late Atokan Stage	~3 m.y.						
Fire Clay tonstein [late early Atokan]	311 Ma						

Figure 4. – Cyclothem estimates of North American stage durations and boundary dates based on numbers of assumed 400-k.y. cycle groupings. A: Using original greater number of cycle groupings (2002) closer to the means of Appalachian radiometric dates. B: Using fewer cycle groupings, based on new information mentioned in text. Assumptions are underlined.

of 311 Ma without even including the middle and upper Atokan Stage. Even assuming an exact 100-k.y. cycle period, this computation produces a 6.4-m.y. duration for the Desmoinesian and Missourian, which is still incompatible with the late early Atokan Appalachian date. Another interpretation of these data [not mentioned in 2002] is possible from the computations in Figure 5A where the 15 major cycle groupings in the 6-m.y. duration of the Virgilian yield exactly the expected 400-k.y. cycle period for these groupings, whereas the 30 major cycle groupings in the 3-m.y. duration of the Desmoinesian plus the Missourian yield exactly the 100-kyr cycle period of the next smaller orbital parameter, suggesting an abrupt change in dominant cycle period at the Missourian-Virgilian boundary. However, the major 'Kansas-type' cyclothems that are considered to more closely represent the 400-k.y. period dominate the Missourian and most of the Desmoinesian but only the lower part of the Virgilian, whereas the upper Virgilian is strongly dominated by only the cyclothems of lesser scale [particularly the minor cycles], and this fact argues strongly against this interpretation. The more recent data recognizing fewer major groupings (Fig. 5B) does not change the essence of this argument, but rather increases the period of the major cycle groupings to 600 k.y. in the Virgilian, which is half again as long as the longest orbital parameter. Note also that although the newer cyclothem groupings bring the estimated boundary ages closer to the older southwestern dates of Rasbury et al. (1998), the closest ends of the error ranges for those dates are still 3 to 4 m.y. older than the recomputed boundaries. [Compare the cyclothem-estimated Carboniferous-Permian boundary of 296 Ma to the youngest end of southwestern error range of 299 Ma, and the cyclothem-estimated Missourian-Virgilian boundary of 300 Ma to the youngest end of the southwestern error range of 304 Ma (Fig. 4B, 5B)].

Significance of Dates for Correlation of Boundaries

The most significant radiometric dates for the Carboniferous-Permian boundary should be obtained from the southern Urals where that boundary is officially defined by an event in a conodont lineage. However, the zircons that Davydov et al. (2002) recently reported from volcanic ashes in successions spanning that boundary there have not yet been dated, according to Davydov (verbal communications, 2003). He also indicated that the SHRIMP U-Pb dates of zircons previously reported by Chuvashov et al. (1996) from that region may be 3 to 4 m.y. older than stated, which means that the estimate of 292 Ma for the Carboniferous-Permian boundary that Menning et al. (2000, figure 7) based on interpolation between dates of 300.3$\pm$3.2 Ma at the 'Moscovian-Kasimovian boundary' and 290.6$\pm$3.0 Ma in the lower Asselian [=lowermost Permian] would be 295-296 Ma, which is where my current estimate now has it. However, Davydov also informed me that the ~300 Ma date listed as 'Moscovian-Kasimovian boundary' by Chuvashov et al. (1996) is not well constrained biostratigraphically, but rather could be anywhere from late Moscovian to mid-Gzhelian in age, including the entire Kasimovian. Therefore, even though the late Moscovian can be correlated with the late Desmoinesian, and the Virgilian can be correlated with the Gzhelian by means of conodonts (Heckel et al., 1998), this date cannot constrain the Moscovian-Kasimovian boundary as well as I thought last year.

New dates from the continental type Stephanian in the French Massif Central are reported by Becq-Giraudon and Bruguier in this Newsletter. These are U-Pb dates that range from 295$\pm$5 to 298$\pm$5 Ma, which they combine to give a weighted mean of ~298$\pm$2 Ma. These and

A. 2002 CYCLOTHEM EVALUATION OF SOUTHWESTERN DATES RELATIVE TO APPALACHIAN TONSTEIN DATE

Southwestern dates, plus earliest Appalachian date	Date/ Duration	# of all cycles	# of all cycles per m.y.	Average cycle period	# of major cycle groupings	# of major cycle gpgs. per m.y.	Average cycle grouping period
Carboniferous-Permian Boundary as estimated	**301±2**						
Interval is entire Virgilian	**~6 m.y.**	**50**	**8.3**	**120 k.y.**	**15**	**2.5**	**400 k.y.**
Missourian-Virgilian Boundary as estimated	**307±3**						
Interval includes entire Missourian, Desmoinesian and mid and late Atokan	**~4 m.y.** [est. **3*** for Mo.+ Ds.]	**67 Msou. + Desm.**	**22.3**	**45 k.y.**	**30 Msou. + Desm.**	**10**	**100 k.y.**
Fire Clay tonstein [late early Atokan]	**311±1**						

B. 2003 CYCLOTHEM EVALUATION OF SOUTHWESTERN DATES RELATIVE TO APPALACHIAN TONSTEIN DATE

Southwestern dates, plus earliest Appalachian date	Date [w. error range] /Duration	# of all cycles	# of all cycles per m.y.	Average cycle period	# of major cycle groupings	# of major cycle gpgs. per m.y.	Average cycle grouping period
Carboniferous-Permian Boundary as estimated	**301±2 [299-303]**						
Interval is entire Virgilian	**~6 m.y.**	**50**	**8.3**	**120 k.y.**	**10**	**1.7**	**600 k.y.**
Missourian-Virgilian Boundary as estimated	**307±3 [304-310]**						
Interval includes entire Missourian, Desmoinesian and mid and late Atokan	**~4 m.y.** [est. **3*** for Mo. + Ds.]	**67 Msou.+ Desm.**	**22.3**	**45 k.y.**	**20 Msou. + Desm.**	**6.7**	**150 k.y.**
Fire Clay tonstein [late early Atokan]	**311±1**						

***** retaining roughly same ratio of Missourian + Desmoinesian to middle + upper Atokan time as in Figure 4, without using fractions of m.y.

Figure 5. – Evaluation of southwestern U. S. radiometric dates (Rasbury et al., 1998) relative to older Appalachian tonstein date. A: Based on old data used in 2002. B: based on new data presented herein.

other recent dates mentioned in their article are consistent with the ~298 Ma U-Pb date reported on Scale A in Menning et al. (2000, Fig. 6). These are only slightly younger than the Ar/Ar plateau dates of ~300 to ~303 Ma reported for the Stephanian on Scale B in Menning et al. (ibid.) from the Saar region, but are closer than the older Westphalian U-Pb and Ar-Ar plateau dates are to one another. Even the older Stephanian Ar-Ar dates on Scale B [which Menning et al. (2000) state should be used] compared with the newly recalibrated North American dates (Fig. 4B) indicate that the Stephanian is more likely equivalent to the entire Missourian [303-300 Ma] plus perhaps the lower Virgilian [300-304 Ma], instead of just the lower Missourian, as I suggested last year. The European workers at the Potsdam meeting agree with Menning et al. (2000) that the top of the Stephanian, as currently identified, is still below the defined top of the Carboniferous.

Estimates of Boundary Dates

Based on the regrouping of presumed 400-k.y. cyclothems as outlined in the discussions above, I present below an updated summary of likely boundary age estimates and durations of North American Pennsylvanian stages at our current state of information (Fig. 4B):

Virgilian-Permian boundary:		296 Ma
Virgilian Stage	4 m.y.	
Missourian-Virgilian boundary		300 Ma
Missourian Stage	3 m.y.	
Desmoinesian-Missourian boundary		303 Ma
Desmoinesian Stage	5 m.y.	
Atokan-Desmoinesian boundary		308 Ma
Atokan Stage	5 m.y.	
Morrowan-Atokan boundary		313 Ma
Morrowan Stage	7 m.y.	
Mid-Carboniferous boundary		320 Ma

The Mid-Carboniferous boundary is taken directly from Scale B of Menning et al. (2000, figure 6). Based on the discussions above, in combination with the ongoing work in correlating the Russian stages with the North American stages (e. g., Heckel et al., 1998; Groves et al., 1999), the new estimated dates for boundaries and durations of the Russian stage names are presented below:

Gzhelian-Permian boundary		296 Ma
Gzhelian Stage	4 m.y.	
Kasimovian-Gzhelian boundary		300 Ma
Kasimovian Stage	4 m.y.	
Moscovian-Kasimovian boundary		304 Ma
Moscovian stage	8 m.y.	
Bashkirian-Moscovian boundary		312 Ma
Bashkirian Stage	8 m.y.	
Mid-Carboniferous boundary		320 Ma

The Kasimovian-Gzhelian and Missourian-Virgilian boundaries are nearly coincident (Heckel et al., 1998). I assigned the age of 304 Ma to the Moscovian-Kasimovian boundary because it currently appears to be about two cyclothems older than the Desmoinesian-Missourian boundary based on preliminary conodont correlations (Heckel et al., 1998). I used the 312-Ma date for the Bashkirian-Moscovian bound-

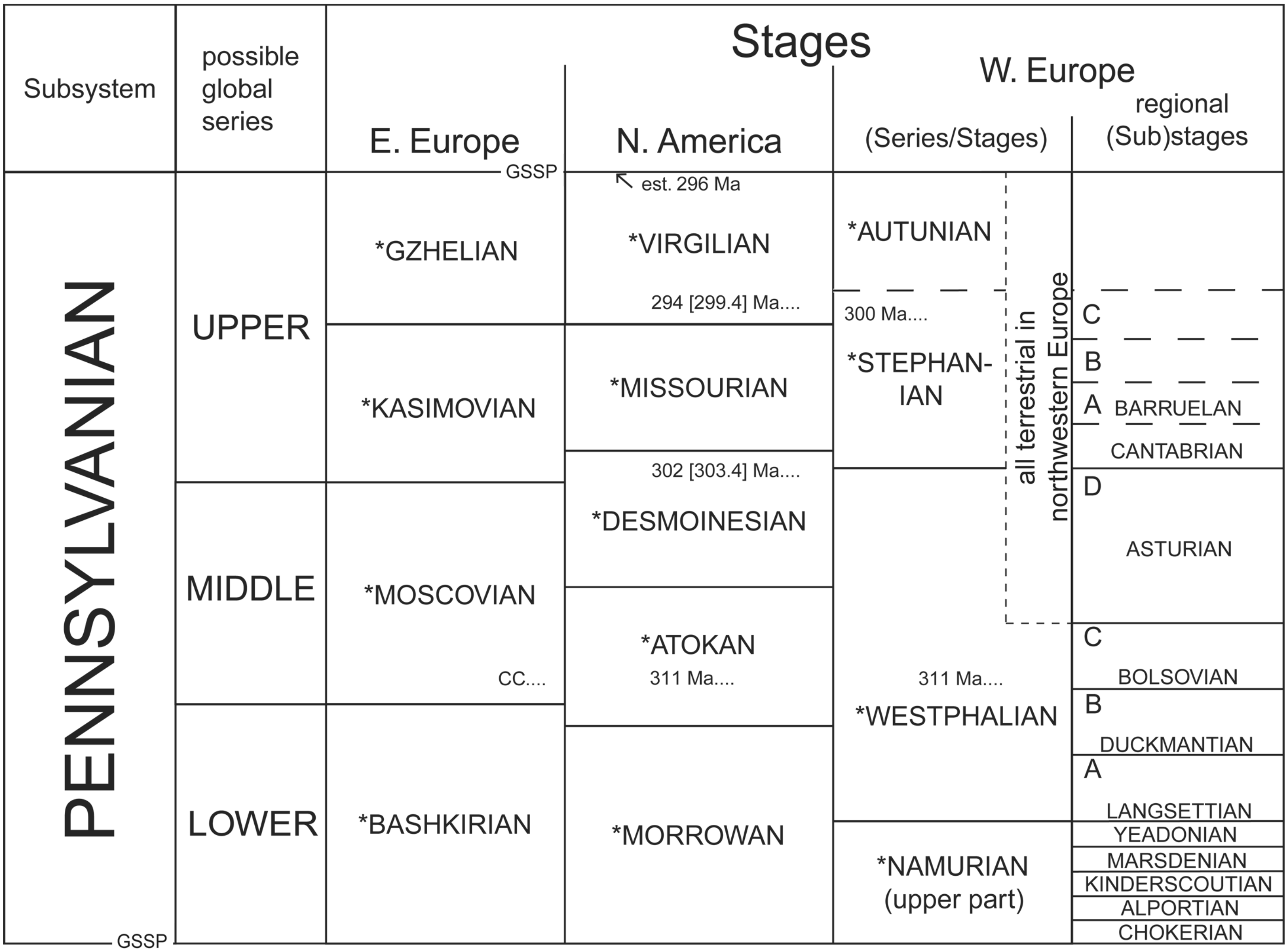

Figure 6. – Updated graphic chart of Pennsylvanian stages showing radiometric dates from Appalachian succession in North America. Older Appalachian date of 311 Ma is consistent with radiometric dates in western European marine succession around Westphalian B-C boundary (Menning et al., 2001), which is tightly correlated with lower Moscovian using conodonts [CC]. Means of younger Appalachian dates are shown with cyclothem-recalibrated figures in brackets. European dates shown are from Scale B of Menning et al. (2000, Fig. 6). Stephanian C date of 300 Ma suggests that much of Virgilian [and Gzhelian] is early Autunian rather than late Stephanian. Vertical axis is not scaled exactly to time as represented by the dates.

ary shown in Menning et al. (2001) because it is well correlated by conodonts above the basal Moscovian with the 309-311-Ma dates they show for the Bolsovian of central Europe. The 314-Ma date that was used by Groves et al. (1999) for the Mid-Carboniferous boundary is close to that of Scale A of Menning et al. (2000, figure 6), which they specifically stated are minimum ages, whereas I am using their Scale B, the maximum ages to be used normally, and it appears more reasonable as outlined in the discussion above.

Conclusions

It appears from all this material that the biostratigraphically well constrained boundary dates within the Pennsylvanian Subsystem provided above are quite closely coincident between North America and both western and eastern Europe near the mid-Westphalian B-C [Duckmantian-Bolsovian] boundary (Fig. 6). Specifically, the 311-Ma late early Atokan Fire Clay tonstein date from the Appalachian is correlated near the Westphalian B-C boundary, which is shown by Menning et al. (2001) to be dated also at 311 Ma, based on several 309-311-Ma dates within the middle and lower Bolsovian. They also show that the basal Bolsovian is correlated with a horizon just above the basal Moscovian of eastern Europe by means of identical conodont faunas. At higher levels, however, the apparent coincidence of the North American and eastern European dates that I suggested in 2002 is no longer well supported, because the SHRIMP U-Pb dates may be older than stated, and the Moscovian-Kasimovian boundary date is not as well constrained as originally believed. It is interesting that the increase in the estimated age of the Carboniferous-Permian boundary to ~296 Ma caused by the regrouping of the North American Midcontinent cyclothems is consistent with the SHRIMP-adjustment increase to 296 Ma of the Menning et al. (2000, Fig. 7) 292-Ma interpolated date for the Carboniferous-Permian boundary in the marine eastern European succession. Nonetheless, the 300-Ma Ar-Ar plateau date in northwestern Europe reported from the late Stephanian [traditionally regarded as highest Carboniferous], still suggests that much of the Lower Rotliegend [lower Autunian] of northwestern Europe is late Carboniferous, as Menning et al. (2000, p. 29) explained.

In summary, I want to emphasize that even the newer dates for the boundaries of the marine-based Pennsylvanian stages given above are still only estimates derived from the radiometric dates from marine successions that appear most consistent with one another and with the currently most reasonable grouping of cyclothem data from the most complete marine succession, the North American Midcontinent. They are still dependent on the accuracy of the well-correlated 311±1 Ma Appalachian tonstein date, but they seem to be the most reasonable estimates to be used until more precise and accurate radiometric age dates from biostratigraphically constrained marine successions become available.

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Defining boundary stratotypes - Speciation, migration, and extinction

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Biostratigraphy is **the** tool to define boundary stratotypes for regional or worldwide use, while isotope ages, magnetostratigraphy, sequence boundaries, and paleoclimatic changes aid and improve the result if and where they are available (Remane et al., 1996). These other methods have their own limitations and are not as generally applicable as biostratigraphy. This situation has been unchanged since William Smith discovered the principles of biostratigraphy around 1800 (Hancock, 1977). What has changed in the meantime is the fact that our understanding of organisms has increased and we have knowledge of mechanisms behind the observed changes while earlier stratigraphers had to rely on empirical observations alone. As a consequence the Carboniferous-Permian boundary is now defined by one evolutionary step in a lineage. However, evolutionary theory and the understanding of ecology and paleoecology have progressed and we have to question this concept and discuss it. Good summaries of evolutionary theory and ecological principles, especially in the context of Earth history, can be found in textbooks of historical geology (for example: Prothero and Dott, 2002, p. 60-68; Stanley, 1999, p. 91-119).

Modes of Speciation

Slow changes in evolutionary lineages do occur and are known as phyletic gradualism, but are only one and apparently the less common mode of evolution. Actually, in lineages showing phyletic gradualism one will see a trend in shape or size without a clear-cut boundary. In these cases the line between the two species has to be drawn by definition, in other words, artificially. We also have to be sure that the observed gradual changes are not reversible phenotypic changes in response to fluctuations of the environment. Therefore, lineages that show phyletic gradualism are unsuited for the definition of stratigraphic boundaries unless large numbers of specimens are available for proper statistical treatment and we are willing to accept artificially defined boundaries.

Another mode of speciation is the formation of sibling species that often can be difficult to distinguish for a long period of time. When they become distinguishable they will exist in different places within the geographic range of the original organism that might be worldwide. Thus, one would see a change from a worldwide species, or a species of wide areal extent to several species that occur in more restricted areas. It is unlikely that the recognizable morphological changes in the different sibling species would all occur at the same time. Thus, this type of speciation is unsuitable for the definition of stratigraphic boundaries of wide significance because one is dealing with the origination of several or many derived species and the observed change will be diachronous in nearly all cases.

The origination of a new species in the same area where the original species survives (sympatric speciation) is rare and in most circumstances impossible. The reason is that species live in the areas to which they are adapted and environmental pressures restrict the species by selection to the design that works in this environment. Thus, any new mutation is most likely to be selected against or eliminated through competition with the characters of the incumbents. If a sequence of mutation occurs that leads to a new species in the same area as the old species, an auto-ecological barrier must be created, i.e., the new species uses a different ecological niche. The new species will originate in a particular area and its first appearance will represent a migration event everywhere else.

Most commonly speciation occurs in **small isolated populations**. In such a situation, mutations accumulate rather rapidly over a much smaller number of generations than in a large population. Small isolated populations, however, are rarely, if ever, fossilized and are therefore invisible to us. Furthermore, most small isolated populations become extinct before they can expand. However, in the cases where a new species (or higher taxon) originates in a small isolated population and the barrier(s) is(are) removed by geological processes, we can expect the new species to expand rapidly. Thus, we need some breeching of a barrier, be it topographic or climatic, so that the new species can spread over a large area, maybe even worldwide. It has been observed that the migration of organisms across a continent can occur over a short time span (50-200 years), i.e., geologically instantaneous. This has been proven most dramatically by species brought by humans to North America, for instance the horse and the zebra mussel.

The moment a species is common in a widespread area, it will become fossilized and found in the record. This means that the absolute majority of first-appearance datums (FADs) are migration events. These migration events can represent the spread of a recently originated new species from a small isolated population, or the wide distribution of a species that beforehand was restricted to an area but can now spread due to removal of barrier or change of climatic conditions.

There are still other mechanisms of species (or higher taxa) origination, especially in plants. These other cases include the instant origination of a different taxon of plants through the formation of a polyploid organism. However, the ultimate mechanism of appearance in the record is always the same, namely the geologically "sudden" common occurrence of a species or higher taxon through migration from the point of origin or breaching of a barrier.

The last appearance datum (LAD) of a species represents its extinction be it local or widespread (see for instance Lemon, 1990, p. 210-235; or Agterberg and Gradstein, 1996 for the resulting uncertainty). A LAD can reflect a change in the environment (climatic or geological) or a biological event (illness, predation, etc.). Both first appearance datums (FADs) and last appearance datums (LADs) represent bio-events that occur in a certain time sequence in a section. *Those **FADs and LADs** that are **found in the same consecutive stratigraphic order in many sections** are useful for biostratigraphic correlation.*

Selecting and Defining a Boundary

The different requirements for the **selection** of a boundary stratotype have been presented in Salvador (1994, p. 91) and Remane et al. (1996, p. 79). The requirement of concern in this discussion is the necessity for "abundance and diversity of well-preserved fossils throughout the critical interval" (Remane et al., 1996). The actual level for the global boundary — the "golden spike" — will be based on a "marker event of optimal correlation potential" (Remane et al., 1996) which may be a FAD or LAD of a fossil but could also be a magnetic reversal or a geochemical or isotope signal in the Global Boundary Stratotype Section to define the **Global Boundary Stratotype Section and Point (GSSP)**.

The publications by Salvador (1994) and Remane et al. (1996) are less specific on the question **how to define the boundary** so that correlations can be achieved. However, the methods developed by quantitative stratigraphy and graphic correlation (see for instance Lemon, 1990, p. 210-235; or Agterberg and Gradstein, 1996; and sources cited therein) are readily available and the obvious choice. To define a boundary one has to record the sequence of bio-events (= FADs + LADs) in the section for a significant stratigraphic distance below and above the selected level. Thus, a GSSP is selected as a point in a specific section but its position is then defined by a specific point in a consecutive stratigraphic order of first and last appearances of fossils. This consecutive stratigraphic order of FADs and LADs should be determined for as many groups of fossils as possible and all these separate consecutive stratigraphic orders of FADs and LADs for the different groups together will define the boundary. The use of many groups will increase the usefulness of the definition and the ability to correlate with other sections. This method is implied by the publications of Salvador (1994) and Remane et al. (1996).

Discussion

Anybody who has plotted bio-events in stratigraphic order knows that a few FADs and LADs might occur in a slightly different order in different areas. Thus, any FAD or LAD out of sequence to the GSSP type section will have to be removed from consideration. This means that we need the largest number of FADs and LADs in the type area to correlate it to the largest number of other areas. This approach requires that in the type area all groups of organisms will be studied that are present, so that we know the FAD and LAD sequence for the largest number of higher taxa. Then we will be able to correlate with other environments or the same environment on many different continents.

We need an intensive discussion of stratigraphic principles and methods in light of their history and recent development together with evolutionary theory and ecological/paleoecological insight to come to a practice of establishing GSSPs and correlating sections in general that gives the most practical and stable results. This is especially important in light of the request by the International Commission on Stratigraphy (ICS) to have all GSSPs selected by 2008 (Heckel, 2002).

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Report on the Upper Viséan-Serpukhovian conodont zonation in South China

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Upper Viséan and Serpukhovian (equivalent to the Duwuan in China) marine sediments are widely distributed and well developed in South China, especially in Guizhou and Guangxi. In many places, such as at the Nashui section near Luodian, Guizhou and the Baping section near Nandan, Guangxi, they form a continuous sequence of limestone containing conodonts and foraminifers, providing an excellent opportunity to study of the Viséan-Serpukhovian and Mid-Carboniferous boundaries and the conodonts of this interval.

Only a few papers, including Wang et al. (1987), Dong et al. (1987), Wang and Higgins (1989), Wang (1990), and Zhang (2000), have reported on the conodont zonation of this interval in South China. They can be summarized in descending order as follows: *Gnathodus bilineatus bollandensis* through *Lochriea nodosa* zones. The present authors collected conodont samples systematically and abundantly from the Upper Viséan to the base of the Upper Carboniferous (Luosuan of China) in the Nashui section, near Luodian, Guizhou. The purpose of these studies is to investigate the Upper Viséan and Serpukhovian conodont zonation, which can be correlated throughout the world. The development of an Upper Viséan to Serpukhovian conodont zonation of the Nashui section is shown in Table 1.

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Conodont Zonation

The reference section for the Upper Viséan and Serpukhovian in South China is the Nashui section, located on the side of the Wangmo-Luodian highway, about 45 km southwest of Luodian. Strata in the Nashui section are mainly composed of black, dark-grey and grey, thin-to medium-bedded limestone. The conodont zonation in the Nashui section (in descending order) is as follows (Fig. 1):

Bashkirian (Luosuan of China)	*Declinognathodus noduliferus* Zone
Serpukhovian (Duwuan of China)	*Gnathodus bilineatus bollandensis* Zone
	Lochriea cruciformis Zone
	L. ziegleri Zone
Upper Visean (Tatangian of China)	*L. nodosa* Zone

Declinognathodus noduliferus Zone

This zone represents the base of the Luosuan in the Nashui section, beginning from sample 25. The base of this zone is marked by the first occurrence of *Declinognathodus noduliferus* or *D. lateralis,* associated with *Gnathodus bilineatus bollandensis, G. bilineatus bilineatus, Lochriea commutata, L. multinodosa, L. nodosa,* and *L. senckenbergica*. The base of this zone, which is very close to the base of the *Millerella marblensis-Eostaffella postmosquensis* foraminifer Zone, is recommended as the base of Bashkirian (Luosuan of China).

Gnathodus bilineatus bollandensis Zone

This zone, represented by samples N17-24, occupies an approximately 25m interval. The base and top of this zone are marked by the first occurrences of *Gnathodus bilineatus bollandensis* and *Declinognathodus noduliferus* or *D. lateralis,* respectively. Other common species include *Gnathodus bilineatus bilineatus, Lochriea commutata, L. mononodosa, L. nodosa, L. ziegleri, Mestognathus bipluti,* and *Pseudognathodus homopunctatus.*

<table>
<tr><td colspan="3">This paper</td><td colspan="2">Xiong and Zhai, 1985</td><td colspan="2">Wang et al., 1987; Wang and Higgins, 1989</td><td colspan="2">Zhang, 2000</td></tr>
<tr><td colspan="2">Stages</td><td>Conodont Zone</td><td>Form.</td><td>Conodont Zone</td><td>Stages</td><td>Conodont Zone</td><td>Stages</td><td>Conodont Zone</td></tr>
<tr><td>Bashkirian</td><td>Luosuan</td><td>Declinognathodus noduliferus</td><td>Huashiban</td><td>D. lateralis</td><td>Luosuan</td><td>D. noduliferus</td><td>Luosuan</td><td>D. noduliferus</td></tr>
<tr><td rowspan="3">Serpukhovian</td><td rowspan="3">Duwuan</td><td>Gnathodus bilineatus bollandensis</td><td rowspan="4">Shangruya (part)</td><td rowspan="2">G. bilineatus bilineatus</td><td rowspan="4">Tatangian (part)</td><td rowspan="4">G. bilineatus bollandensis</td><td rowspan="3">Duwuan</td><td rowspan="3">Adetognathus lautus
G. bilineatus bollandensis
A. unicornis</td></tr>
<tr><td>Lochriea cruciformis</td></tr>
<tr><td>L. ziegleri</td><td rowspan="2">G. bilineatus</td></tr>
<tr><td>Visean</td><td>Tatangian</td><td>L. nodosa</td><td>Tatangian</td><td>L. nodosa</td></tr>
</table>

Table 1 Comparison of Upper Viséan to basal Bashkirian conodont zonations at the Nashui section, Luodian, Guizhou.

***Lochriea cruciformis* Zone**

This zone, represented by samples N8-16, occupies an approximately 29m interval in the section. The base and top of this zone are marked by the first occurrences of *Lochriea cruciformis* and *Gnathodus bilineatus bollandensis*, respectively. Other common species include *Gnathodus bilineatus bilineatus, G. praebilineatus, Lochriea commutata, L. mononodosa, L. nodosa, L. senckenbergica, Mestognathus bipluti,* and *Pseudognathodus homopunctatus*.

***Lochriea ziegleri* Zone**

This zone, extending through an approximately 15m interval in the section, is represented by samples N4-7. The lower and upper limits of this zone are marked by the first occurrences of *Lochriea ziegleri* and *L. cruciformis*, respectively. Other important species include *Gnathodus bilineatus bilineatus, G. praebilineatus, Lochriea commutata, L. mononodosa, L. nodosa, Mestognathus bipluti,* and *Pseudognathodus homopunctatus*.

***Lochriea nodosa* Zone**

This zone occurs at the base of the section. The first occurrences of *Lochries nodosa* and *L. ziegleri*, respectively, indicate the lower and upper boundaries of this zone. Other important species include *Gnathodus bilineatus bilineatus, G. praebilinatus, Lochriea commutata, L. mononodosa, Mestognathus bipluti,* and *Pseudognathodus homopunctatus.*

Viséan-Serpukhovian Boundary Interval

As mentioned by Nikolaeva et al. (2002), the closest level to the ammonoid-based Viséan-Serpukhovian boundary in the South Urals section is the base of the *Lochriea cruciformis* Zone. Therefore, the base of the *Lochriea criciformis* Zone is recommended as the base of Serpukhovian. However, in the Nashui section, the first occurrence of *Lochriea ziegleri* (N4) is very close to the base of the *Eostaffella postmosquensis* foraminifer Zone (N3), which is the index zone for the Duwuan in China. In China, the Duwuan includes only a single foraminifer zone, the *Eostaffella postmosquensis* Zone, which is equivalent to the *Eumorphoceras* ammonoid Zone (Zhang, 2000). Therefore, the present authors suggested that the first occurrence of *Lochriea ziegleri* is a good marker for the base of Serpukhovian or Duwuan in China. As noted by Nikolaeva et al. (2002), the species *Lochriea cruciformis* is rare in the South Urals and its representatives from that region are morphologically different from the type specimen and are somewhat similar to *L. costata* and *L. ziegleri*. They also noted that the species *Lochriea ziegleri* is more frequent and is probably a better choice as a boundary marker. In the evolutionary lineage *Lochriea nodosa-L. ziegleri-L. cruciformis,* the morphological changes from *L.*

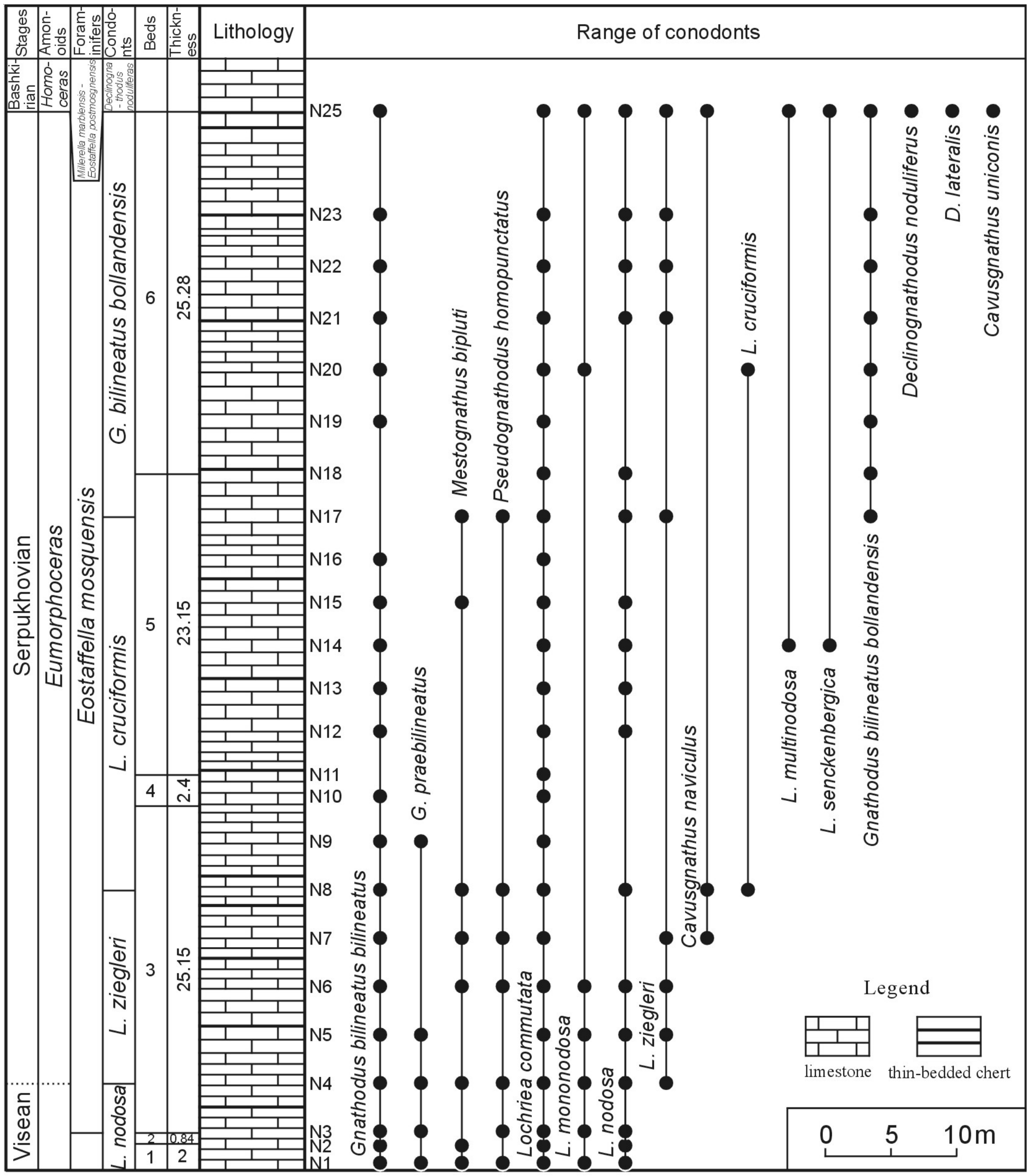

Fig. 1 Vertical distribution of conodont species and conodont zones from the Upper Viséan to the base of the Bashkirian in the Nashui section, Luodian, Guizhou.

nodosa to *L. ziegleri* are much more obvious than those from *L. ziegleri* to *L. cruciformis.* In the Nashui section at Luodian, *Lochriea ziegleri* is extremely abundant and characteristic. It is very easily distinguished. Therefore, *Lochriea ziegleri* is the index species of the base of Serpukhovian or Duwuan.

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Additional comments on the Upper Paleozoic glaciations in Argentina

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The bipartition of the Carboniferous System/Period adopted by the International Commission on Stratigraphy is useful for sequences in the Northern Hemisphere, but does not fit well with sequences of the Southern Hemisphere, where glaciations induced endemism of the biota. For example, the Mid-Carboniferous boundary in the paleoequatorial standard is marked by conodonts and goniatitids that are unknown in the Gondwana province, where a more natural division is suggested by the climatic changes. The Late Paleozoic marine deposits of Argentina show five major faunal groups, each associated with a period of climatic stasis, either glacial or non-glacial. In this sketch, non-glacial (pre-glacial and interglacial) “warm” faunas are closer to paleoequatorial faunas, while endemic “cold” faunas can be matched only with Australian faunas.

The latest findings in the Andean Belt and central Patagonia furnish new information about the Carboniferous and the Early Permian glaciations.

Late Mississippian-Early Pennsylvanian

The Carboniferous glaciation in southern South America is recorded in marine and continental deposits scattered from Bolivia to Patagonia. Indirect evidence suggests that ice sheets covered a vast territory of southeastern South America, probably equivalent in extent to that which had Early Permian ice sheets.

At least four discrete glacial phases occurred during this epoch (González, 2001). In the Andean region the most remarkable record of these episodes is the San Eduardo Formation, which can be regarded as a standard sequence for the Carboniferous glaciation of Gondwana (González, 1990). There, three glacial stages are interbedded with marine sediments which yield fossil faunas much like eastern Australian faunas, and date the oldest glacial stage to the latest Viséan; that is, before the Mid-Carboniferous boundary. The rest of the glacial deposits correspond to the *Levipustula levis* Zone. However, in this region the Carboniferous glacial sequence is incomplete, being discordantly overlapped by Late Pennsylvanian sediments.

The Pampa de Tepuel Formation of central Patagonia probably contains the entire record of the Carboniferous glaciations in marine facies. The whole biochron of *Levipustula levis*, which in the upper beds of this formation is associated with the Westphalian goniatites *Wiedeyoceras argentinense* and *Glaphyrites* sp. (Riccardi and Sabattini, 1975), can also be documented. In Australia the *L. levis* Zone is regarded exclusive of the Namurian (Roberts et al., 1995), probably because glacial deposits of Westphalian age there are continental. It seems that the upper portion of this biozone is lacking in the New England Orogen, just as is the case in the Precordilleran region of western Argentina. Glacial beds of the Upper Pampa de Tepuel are probably equivalent to the Westphalian tillites of eastern Australia.

In the Pampa de Tepuel Formation discrete glacial phases are less clearly differentiated than in western Argentina (Suero, 1948; González Bonorino et al., 1988). Littoral facies of this formation at the northern border of the basin show striated glacial floors in soft sediment (González et al., 1995). Another glacial pavement was recently found in outcrops of similar facies at the southeastern border of the basin (González et al., in prep.). This evidence reveals that glaciers entered into the Languiñeo-Genoa embayment, forming a floating ice shelf, and that a large continental area of Patagonia to the north and east of the Languiñeo-Genoa Basin was covered by ice sheets.

Late Pennsylvanian

Late Pennsylvanian (Upper Westphalian to Stephanian) deposits do not show evidence of glaciation. Also, continental areas supported abundant vegetation (*Nothorhacopteris* flora), with formation of soils and coal seams. During this interglacial period, two “Pacific” ingressions flooded the Andean Belt, and rising sea water temperatures caused a southward penetration of “warm” elements from the north: the *Balakhonia-Geniculifera* and *Buxtonia-Heteralosia* faunas. More than 3000 m of sediments yielding these flora and faunas, the Agua Negra Formation, were deposited in the Frontal Cordillera. In the Andean Belt the Late Pennsylvanian sequence is separated from underlying and overlying deposits by unconformities.

In central Patagonia, however, this interglacial period is not clearly recognised. In this region the stratigraphic equivalents are the lower 500 m of the Mojónde Hierro Formation. This section is intercalated between the *L. levis* Zone and the *Costatumulus amosi* Zone without unconformities. However, no remains of the “interglacial faunas” have so far been found in these sediments, perhaps due to rising sea levels at the end of the Carboniferous glacial period.

Early Permian

The base of the Permian System in Argentina is assumed to be indicated by the appearance of *Costamulus amosi*. It has been argued that this brachiopod lived during the beginning, namely the first stage, of the Asselian glaciation, and that it is older than the Tastubian *Eurydesma* fauna (González, 1993). Although Taboada (2001) and Dickins et al. (1993) believe that both faunas were coeval, assuming they were adapted to different environmental conditions (mainly temperature), in Argentina these two faunas do not occur in the same sequence, and there are reasons to believe that they are separated by a gap representing the younger portion of the Asselian.

The Early Permian glaciations affected central Patagonia and western Argentina, although seemingly less severely than the Carboniferous glaciation. Glaciomarine sediments occur in the lower part of the *C. amosi* Zone in the Agua del Jagüel Formation, east of Uspallata. The most recent findings show that a glacial member is also present in the lower Mojón de Hierro Formation in central Patagonia. Both occurrences can be attributed to the the Uspallata glacial phase (González, 2001), which is considered the oldest Asselian glaciation.

The recognition of earliest Asselian glacial deposits in western Argentina and Patagonia supersedes the theory of migration of glacial centers (Caputo and Crowell, 1985). The absence of the youngest Early Permian glacial stages in southwestern South America is probably a consequence of progressive, though rapid, contraction of the glaciated area preceding the end of the "ice age." On the other hand, these earliest Permian strata are unconformably overlain by Permo-Triassic sediments in western Argentina, and by Early Jurassic marine deposits in Patagonia. It cannot be overlooked that these terrains were exposed to erosion during most of the Permian (as well as the entire Triassic in Patagonia), and that during such a long interval glacial deposits equivalent to those of the Paraná, Sauce Grande, and Malvinas (Falkland) basins, eventually deposited in these areas, could have been eliminated by erosion.

In the Sauce Grande Basin of eastern Argentina, deposits of the post-glacial transgression which yield the *Eurydesma* fauna overlay tillites of the Sauce Grande Formation. These tillites and the Dwyka Tillite were deposited during the last glacial stage of the Early Permian. The *Eurydesma* fauna of eastern Argentina is lacking in the Paraná Basin, and there is no clear evidence of marine connection between this basin and the Sauce Grande Basin. Moreover, a large continental area to the west was interposed between the Sauce Grande Basin and the region of western Argentina and Patagonia (compare Frakes and Crowell, 1968 and Rocha Campos, 1970). Moreover, the "*Eurydesma* sea" of eastern Argentina extended to the Kalahari Basin, but it was not linked with the region of Australia and India as postulated by Shi and Archbold (1993). Instead, this sea had to be closed to the east, probably in the eastern Karroo Basin, as shown by a strong faunal diversity gradient (González, 1989). Most probably, a paleogeographic connection was established between those regions *via* an arm of sea, the "proto-Atlantic," which extended between the El Cabo region of South Africa and the Malvinas (Falkland) Islands.

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Did the "Ostrogsky episode" really exist?

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In 1948 M.F. Neuburg pointed out that near the end of the Early Carboniferous [Mississippian] in the Kuznetsk Basin, the change of "lepidophytalean" plant assemblage to the "cordaitean" assemblage had begun. This change of plant assemblages was finished in the lower part of Mazurovsky Suite of the modern regional stratigraphical scale, although the most prominent extinction of lepidophytes took place in the second (II) of three phytostratigraphical horizons, distinguished by Neuburg in the underlying Ostrogsky regional series (Fig. 1).

Twenty years later, Neuburg's disciple S. V. Meyen (1968) concluded that such a change took place throughout the whole of Angaraland and was probably connected with climate. According to him, "the predominance of arborescent lepidophytes with perennial, manoxylic trunks in the first third of Ostrogsky time and in the previous part of the Carboniferous is evidence of frost-free climate. The extinction of such plants, branching reduction, and probable appearance of the leaf abscission in the pteridosperms of *Angaropteridium*-type, which began in the middle of Ostrogsky time, the invariable presence of growth-rings in post-Ostrogsky woods, and some other characters indicate the essential worsening of climatic conditions. The climate humidity was apparently not decreased (as evidenced by the intensification of coal formation), and so the climatic change went in the direction of lowering of mean annual temperatures"

East-European Scale			Regional Scale of Kuznetsk and Minusinsk coal Basins		
System	Series	Stages	Regional series	Suites	Regional floras
Carboniferous	Upper	Moscovian	Lower Balakhonsky	Mazurovsky	Pteridosperm – Cordaitean
		Bashkirian			
			Ostrogsky	Kaezovsky	Postlepidophytean
	Lower	Serpukhovian			
		Viséan		Evseevsky	Lepidophytean
			Minusinsky	Baynovsky	
				Jamkinsky	
				Solomensky	
		Tournaisian		Samochvalsky	
				Altaysky	

◄ Sea transgression

Fig. 1. Modified from: Ganelin, Durante, 2002

(loc. cit., p. 945).

Meyen correlated this floristic event with the sharp change from Culm-like flora to the typical Westphalian-like flora at the base of Namurian B in Western Europe. W. Gothan had called this change "Florensprung." According to Meyen, the correctness of Gothan's conclusions about the great scale of this floristic restructuring is without doubt. At the same time, the Namurian A/B boundary correlates with the Mississippian/Pennsylvanian boundary in North America. "Such critical moments in the history of Angaran and Euramerican floras," – wrote Meyen (loc. cit., p. 946), – "which in sum inhabited the whole hemisphere, do not appear to be only externally analogous to each other. The changes that took place in both floras are so significant that it is difficult to consider them as totally independent and happening at different times. It is also difficult to connect the scale of these phenomena to local palaeogeographical events; more probably one can speak of the influence of global factors." On these bases Meyen correlated the two upper phytohorizons of the Ostrogsky regional series (in the volume that was adopted at that time by S.G. Gorelova) with Namurian B. At the same time he did not exclude the possibility that its lower part may be Viséan in age. Meyen considered the main significance of his article to be in the "stratigraphical correlation of floras by means of the identification of hologenetic or climatic exoecogenetic changes (in the terms of V.N. Sukachov) in their history" (loc. cit., p. 947).

Later, Meyen (1982) called the above-cited cooling episode "Ostrogsky." He supported his primary arguments in favor of its existence by the presence of mottled sediments and evaporites in the earlier Carboniferous deposits of Siberia. Meyen related their formation to arid or semi-arid climate. In his opinion, the appearance of coal-formation after the "episode" indicates not only the cooling, but also the increasing humidity of the climate. This viewpoint is reflected in his "Fundamentals of Palaeobotany" (Meyen, 1987).

The idea of a prominent cooling episode at the end of the early Carboniferous of Angaraland was widely adopted in the literature. Discussions were concentrated mainly on the probable age and correlation of the "Ostrogsky episode" with the other abiotic events. For example, Gastaldo, DiMichele, and Pfefferkorn (1996) correlated the "episode" and the corresponding change of the floristic assemblages in Angaraland with the beginning of Gondwanan glaciation at the Viséan/Namurian boundary. On the contrary, Cleal and Thomas (1999) concluded that the "episode" was Westphalian in age and coincides with the beginning of the decline of the Euramerican coal-forming forests, dominated by large arborescent lepidophytes.

According to Durante (2000), the "Ostrogsky" cooling episode was global and led to the "change from the rich and diversified cosmopolitan Early Carboniferous biota to the rather poor and differentiated Late Carboniferous one" (loc. cit., p. 31). In Angaraland it led to the change from the Late Tournaisian – Early Viséan flora, dominated by thick stemmed lepidophytes, to the impoverished "postlepidophytean" flora. The latter consisted of pteridosperms with leaves of *Abacanidium*-type with cyclopteroid venation of pinnules, and small seeds of *Trigonocarpus*-type, small-stemmed relict lepidophytes, as well as several primitive arthropsids. This flora is distributed in the upper part of Ostrogsky regional series (Kaezovsky Suite) of the Kuznetsk Basin and its analogs in the other regions of central Angaraland. Near the top of Kaezovsky Suite (Middle Bashkirian) it is replaced by "the rather rich and diverse temperate Cordaitean" flora (loc. cit.).

Durante (2000) dated the "Ostrogsky episode" as uppermost Viséan to earliest Serpukhovian. She cited recent data of V.G. Ganelin, who established the age of the endemic brachiopods of the marine transgression at the beginning of Kaezovsky time in the Kuznetsk Basin as latest Viséan. According to Ganelin, this brachiopod assemblage may be correlated with the assemblage of the lower part of Magarsky Horizon (uppermost Viséan) of northeastern Russia (Ganelin and Durante, 2002).

At the same time, Durante (2000) emphasized that, according to V. Havlena (1977, 1982), W. Gothan's "Florensprung" is an artifact, generated by local interruptions of sedimentation and "therefore there is no supporting evidence for the Angaran Ostrogsky Episode coinciding with the Namurian A/B boundary" (loc. cit., p. 32). Before Durante, E.O. Novik and several other palaeobotanists had noted the gradual transition of floral assemblages at this boundary (Meyen, 1968).

In Durante's opinion, the "lepidophytean"/ "postlepidophytean" floral change may be correlated with the analogous change of the thermophilic lepidophyte-dominated flora to the temperate *Nothorhacopteris* flora in Gondwanaland. According to Retallack (1980), the last flora there is uppermost Viséan to lowermost Namurian. Morris (1985) also pointed out that at the end of the Viséan the extinction of endemic *Lepidodendron* flora took place in eastern Australia.

* * *

The study of distribution of the main early Carboniferous plant genera and species of Angaraland, based on concrete palaeogeographical and historical geological background, provides the following considerations.

1. Throughout the whole of Angaraland the transition from the Tournaisian – Viséan "lepidophytean" flora to the late Carboniferous "pteridosperm-cordaitean" flora occurred unequally in various regions, which is reflected in the composition of the Serpukhovian – Early Bashkirian "postlepidophytalean" floral assemblage established by Durante (Ganelin and Durante, 2002). For example, in the Kuznetsk Basin this transition is rather sharp (Meyen, 1968; Durante, 1995, 2000), but in the adjacent Minusinsk Basin, it is, on the contrary, rather gradual (Zorin, 1998). This circumstance does not allow connecting this transition with the same global climatic cause. In spite of the supposed Ostrogsky cooling, such "lepidophytean" floral relics as the thermophylic lepidophyte *Angarodendron* not only survived in the Kuznetsk Basin at least up to the end of Bashkirian time, but also became dominant in the coal-forming plant communities.

The main dominants of the "postlepidophytean" assemblage (*Abacanidium* spp., *Angaropteridium* spp.) are apparently inherited from the previous flora of "thick stemmed lepidophytes" (*Tomiodendron, Angarophloios*). It also shows the mainly ecological character of the "lepidophytean"/"postlepidophytean" floral transition.

2. The change of "lepidophytean" flora to "postlepidophytean" flora in the Kuznetsk Basin may be related to marine transgression at the boundary between Evseevsky and Kaezovsky time (Fig. 1), and not with climatic cooling.

The representatives of the "lepidophytean" flora began to occupy the territory of the Kuznetsk Basin already in the Viséan. The centers of plant distribution occurred in the adjacent region of the Minusinsk Basin. The evidence for this conclusion includes not only the geographical proximity, the presence of probable migration routes, and the age relations of both floras, but also the resemblance of composition of the Viséan floras of the Minusinsk and Kuznetsk basins, which is much closer than that of any other coeval Angaran floras.

A short-term marine transgression at the very end of the Viséan apparently at least seriously disturbed (if not totally destroyed) the thick-stemmed lepidophyte-dominated plant communities in the river valleys and accumulative lowlands. These plant associations were never restored to their previous state. The disturbed biotopes were partly occupied by several local thin-stemmed and small-leaf-cushioned lepidophytes (*Angarodendron* etc.), as well as by pteridosperms with leaves of *Abacanidium* and *Angaropteridium* type. The latter forms produced here, in conditions of topographic isolation, an "outbreak" of speciation.

From the beginning of the Serpukhovian several representatives of the Minusinsk Basin flora continued to penetrate into the territory of the Kuznetsk Basin, which was drained of sea water.

The proximity of a rather warm sea basin and mountain ridges that intercepted rainy air masses, caused the moistening of the climate and formation of coal during Kaezovsky time in the Kuznetsk Basin.

3. The Gondwanan glaciation, which began at the Viséan-Serpukhovian boundary and reached its maximum near the Carboniferous-Permian boundary, caused a global climatic consequence, the formation of the more differentiated system of latitudinal climatic zones, characterized by sharper climatic distinctions between tropical and extra-tropical zones, as well as between the southern and northern extra-tropical zones. One can agree with Durante (2000) that these changes minimally affected the vegetation of the tropical zone. At the same time, the global correlation of floral changes in Angaraland and Gondwanaland that she proposed needs confirmation.

The influence of the Gondwanan glaciation on the extra-tropical floras of the southern and northern hemispheres was evidently essentially "asymmetrical." In Gondwanaland, continental glaciation with the formation of large ice-sheets took place. It caused such phenomena as a replacement of latitudinal plant zones and the formation of peculiar biomes such as *Botrychiopsis* tundra, reconstructed by Retallack (1980). In Angaraland the first traces of ice appeared only in the Late Permian (Chumakov, 1994). This confirms the absence of a northern ice cap and corresponding latitudinal climatic zonality before this time. As a whole, the climate of the northern hemisphere was apparently warmer than that in the southern extra-tropical region, disregarding the local climates of the mountain ridge-protected, isolated intra-continental and coastal lowlands of Angaraland.

It seems probable that the change of "lepidophytean" flora to "postlepidophytean" flora in Angaraland and to the *Nothorhacopteris* flora in Gondwanaland in the middle Carboniferous are only coincident within a large duration of time, as they were caused by different abiotic events. In Angaraland this change could be connected particularly with the ecological expansion and evolutionary radiation of the pteridosperms and cordaitean plants, conditioned by geographical isolation. The lepidophytes with their rather low morphological and ecological plasticity simply could not compete with these plant groups in migration possibilities, as well as in the occupation of disturbed and new biotopes. The process of this change was protracted over nearly all of Serpukhovian and Bashkirian time.

It is important to note that the expansion of Gondwanan glaciation toward the end of the Carboniferous did not lead to subsequent cooling in Angaraland, which would be expected if the "Ostrogskian episode" was really connected to climatic cooling.

The formation of the *Nothorhacopteris* flora was apparently conditioned to some extent by the Gondwanan glaciation. In any case, its floral composition and plant growth-forms evidently changed, depending on the proximity to ice-sheets. In particular, the lepidophytes acquired arborescent habits only in the warmer regions of Gondwanaland, distant from the glaciers (in modern Niger, Peru). Toward the edges of the ice-cap, the general taxonomic diversity of the *Nothrhacopteris* flora also decreased (Gastaldo et al., 1996). It is noteworthy that the change of the "lepidophytean" flora to the *Nothorhacopteris* flora was again not sharp, and was conditioned by various interrelated biotic and abiotic processes.

Thus, the analysis of several Paleozoic floras leads to the question: Did the "Ostrogsky episode" really exist? We suggest that only a more detailed comparative investigation of various Carboniferous floras could provide the definitive answer.

At the same time, it seems probable that the idea of using the identification of global climatic changes in the development of Earth floras as universal levels of stratigraphic correlation has exhausted itself. Such levels are very rare and are represented mainly by boundaries between thermal and glacial eras. The corresponding floral changes were protracted at least through ages, if not whole epochs. The influence of large climatic events on the floras of various latitudes, continents, and regions was essentially different. It is difficult to distinguish the influence of these events from the effects of other independent factors, not to mention the estimation of their role. In this situation, it seems more appropriate to practice the construction and subsequent analysis of scenarios of development of ancient floras with a background of recent palaeogeography, tectonics, lithology, historical geology, and florogenetic data, using the established causal relationships for stratigraphic correlations.

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Correlation of the Moscow Basin Lower Carboniferous with the Carboniferous megafloral zones of the Euramerican palaeofloristic region

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In 1984 R. Wagner proposed a megafloral zonal scale for the Euramerican Carboniferous which combined many previously established zones. In the Lower Carboniferous [Mississippian] he recognised five zones: *Adiantites* Zone, *Triphyllopteris* Zone, *Lyginopteris bermudensiformis – Neuropteris antecedens* Zone, *Lyginopteris bermudensiformis – Lyginopteris stangeri* Zone, and *Lyginopteris larischi* Zone. In my opinion, this zonation is also applicable to the northeast (in palaeolatitude) periphery of the Euramerican palaeofloristic region where the Moscow coal Basin was situated.

* * *

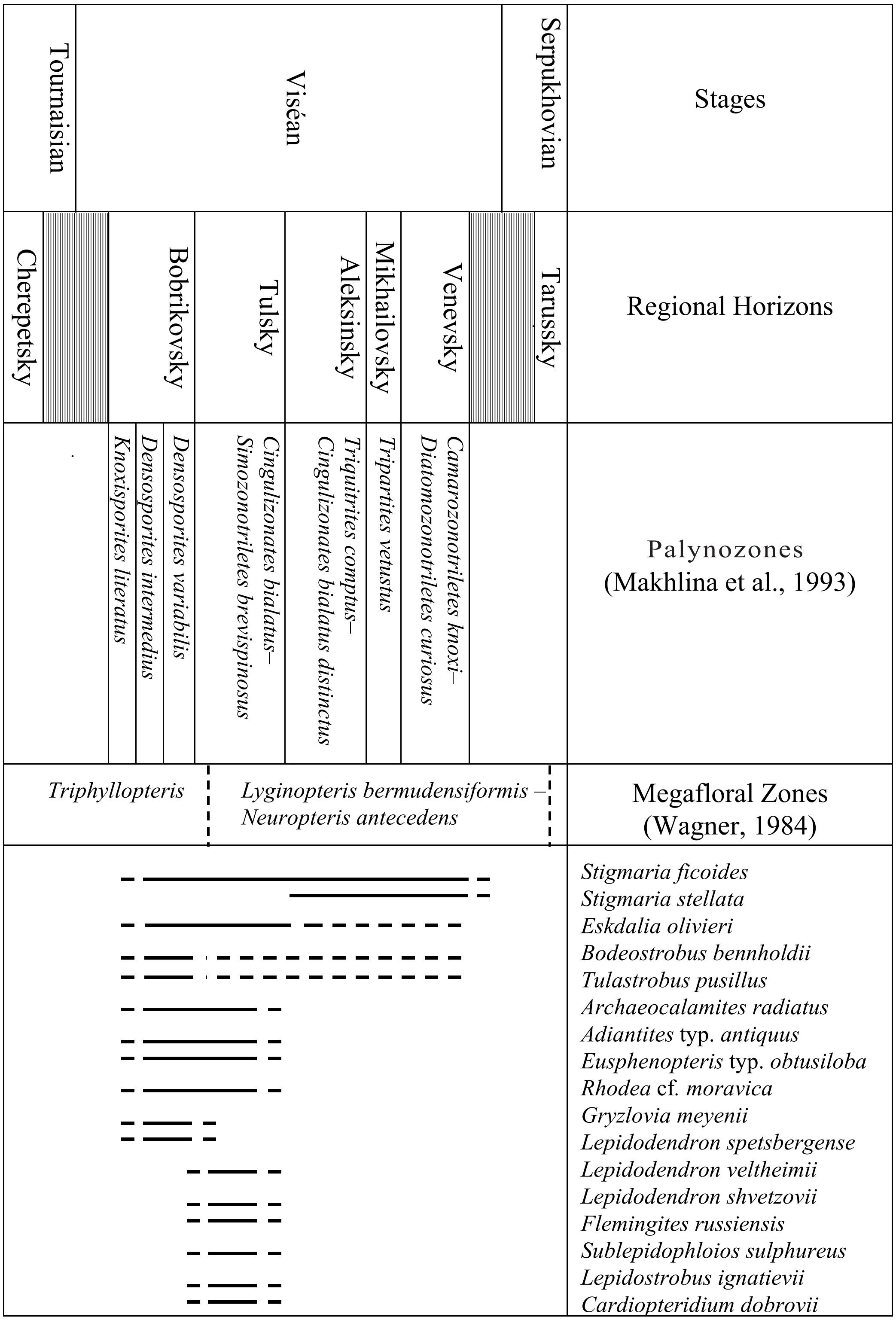
Early Carboniferous floras of the Moscow Basin are closely related to contemporaneous Euramerican floras of East Europe (S.V.Meyen *in* Vakhrameev et al., 1978). Like the European floras, its coenotic composition included (among others) antracophylic (dominated by lepidophytes) and antracophobic (dominated by ferns and pteridosperms) plant associations.

Many plant megafossils of the Moscow Basin flora belong to widely distributed Euramerican species established on the basis of impression/compression material. Among these are: *Archaeocalamites radiatus, Adiantites* typ. *antiquus, Eusphenopteris* typ. *obtusiloba, Rhodea* cf. *moravica, Lepidodendron spetsbergense, L. veltheimii,* etc.

The flora of the Moscow Basin developed in geographic isolation from the floras of southern European basins resulting in a mass appearence of endemics at the generic and species level (e.g., *Eskdalia olivieri, Gryslovia meyenii, Lepidodendron shvetzovii*, *Sublepidophloios sulphureus, Cardiopteridium dobrovii,* etc.), as well as peculiar domination-patterns and plant community spectrums. At the same time, several stratigraphically important European plant groups, such as lyginopterids, are absent or relatively rare.

* * *

Investigation of the floristic sequence in the Moscow Basin makes it possible to recognise two different assemblages, which may be treated as analogues of Wagner's *Triphyllopteris* (T) and *Lyginopteris bermudensiformis – Neuropteris antecedens* (LN; Fig. 1) megafloral zones.



In the Moscow Basin the analogue of the *Triphyllopteris* Zone includes deposits from the Bobrikovsky and the basal part of the Tulsky regional horizons.

Small-cushion lepidophytes of the *Lepidodendropsis* type, which range to the top of *Triphyllopteris* Zone in Europe, are represented in the Moscow Basin by the endemic monotypic genus *Gryslovia*, known only from the Bobrikovsky Horizon.

Other characteristic forms from this interval are *Archaeocalamites radiatus, Adiantites* typ. *antiquus, Eusphenopteris* typ. *obtusiloba*, and *Rhodea* cf. *moravica*. In the antracophilic associations the endemic lepidophyte *Eskdalia olivieri* predominated.

Narrow-cushion lepidodendrons of the *Lepidodendron spetsbergense* type, which are also restricted to the Bobrikovsky Horizon in the Moscow Basin, were described from the Calciferous Sandstone formation of Scotland (Crookall, 1964) and correlated by R. Wagner (1984) with the upper (early Viséan) part of the *Triphyllopteris* Zone.

The base of the *Triphyllopteris* Zone cannot be recognised in the Moscow Basin because it coincides with the marine epoch of regional development.

The analogue of the *Lyginopteris bermudensiformis – Neuropteris antecedens* Zone apparently includes the Tulsky (without its basal part), Aleksinsky, Mikhailovsky, and Venevsky regional horizons. Its base is conditionally traced by the first occurence of the endemic *Cardiopteridium dobrovii* in the basal beds of Tulsky Horizon.

In Tulsky time forms such as *Adiantites* typ. *antiquus*, *Rhodea* cf. *moravica*, and *Archaeocalamites radiatus* persisted, as well as numerous coal-forming *Eskdalia olivieri*. *Rhodea* and *Archaeocalamites* also existed until the end of Venevsky time. The last scarce allochtonous remains of *Eskdalia* are known from limestones of Venevsky–Tarussky age (uppermost Viséan to early Serpukhovian).

Paneuramerican *Lepidodendron veltheimii* and endemic *L. shvetzovii* and *Sublepidophloios sulphureus* first occur in deposits of the Tulsky Horizon. The first species ranges from the basal third of *Triphyllopteris* Zone in western and central Europe and persists up to the top of the Lower Namurian. *Lepidodendron shvetzovii* is known only from the Tulsky Horizon. Forms of *Sublepidophloios sulphureus* type probably also occur also in the Mikhailovsky deposits, but the corresponding data requires confirmation.

From the beginning of Tulsky time most of the species chracterizing the Moscow Basin analogue of the *Lyginopteris bermudensiformis – Neuropteris antecedens* Zone decrease their areas and persisted, apparently, only in small island and coastal refugia, as a result of marine transgression.

The large marine transgression which occurred in Aleksinsky–Venevsky and Serpukhovian time precludes the identification of the upper boundary of *Lyginopteris bermudensiformis – Neuropteris antecedens* Zone in the Moscow Basin.

* * *

The correlations described in the present paper agree well with palynological data from the south flank of the Moscow Basin (Makhalina et al., 1993). In the interval including the Bobrikovsky through Venevsky regional horizons, seven palynozones are recognised (Fig. 1).

In the Bobrikovsky Horizon three regional palynozones are established: *Knoxisporites literatus* Zone (L), *Densosporites intermedius* Zone (I), and *Densosporites variabilis* Zone (V), each characterised by the nominate spore species.

The spore assemblage from the Tulsky Horizon corresponds as a whole to the *Cingulizonates bialatus – Simozonotriletes brevispinosus* Palynozone (BB), and differs drastically from assemblages of the Bobrikovsky Horizon. Small spores with granulate, smooth, or spined exine and usually concave equatorial contour (e.g., *Granulatisporites, Punctatisporites, Leiotriletes, Cyclogranisporites,* etc.) predominate here. The proportion of *Cingulizonates bialatus* and *Schulzospora campyloptera* considerably increases. The lower boundary of the zone coincides with the first occurrence of the zonal index *Simozonotriletes brevispinosus*.

The spore assemblages of the Aleksinsky (*Triquitrites comptus – Cingulizonates bialatus distinctus* Palynozone; CBd), Mikhailovsky (*Tripartites vetustus* Palynozone; Ve) and Venevsky (*Camarozonotriletes knoxi–Diatomozonotriletes curiosus* Palynozone; KC) regional horizons are closely related to the Tulsky assemblage by their general systematic composition, including the above cited characteristic forms.

The uppermost Tournaisian and Serpukhovian deposits of the south flank of the Moscow Basin have no palynological characteristics.

The boundary between the upper Bobrikovsky *Densosporites variabilis* Palynozone and the lower Tulsky *Cingulizonates bialatus – Simozonotriletes brevispinosus* Palynozone can be correlated with the boundary between the *Triphyllopteris* and *Lyginopteris bermudensiformis – Neuropteris antecedens* Zone analogues established above because they probably reflect one and the same floral change. The last event was apparently linked with the decrease of coal-swamp ecosystems caused by the intensification of terrigenous sedimentation and the corresponding change in paleoriver system dynamics (Ignatiev and Mosseichik, 2002).

Many characteristic spore species of Bobrikovsky palynozones (e.g., *Crassizonotriletes trivalvis, C. auritus, C. macroduplicatus, C. planus, C. canaliculatus, Knoxisporites literatus, Eurizonotriletes macrodiscus, E. ciliato-marginatus,* etc.) do not dissappear at the Bobrikovsky/Tulsky Horizon boundary, but rather above this level, showing the necessity to place the upper boundary of the *Triphyllopteris* Zone analogue in the basal part of Tulsky Horizon.

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U-Pb zircon and K-Ar illite radiometric dating of Upper Stephanian continental successions in the French Massif Central. An overview of recent results and its correlation with other occurrences in the Variscan Belt of Europe.

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Introduction

Post-convergence evolution of the Variscan Belt is characterized by the development of numerous intramontane coal-bearing basins. These basins represent isolated troughs closely associated with fault-zones and filled with coarse, clastic, fluvio-lacustrine sediments deposited unconformably on the metamorphic and igneous basement. In the French Massif Central (FMC) sedimentary successions are generally well-preserved and their biostratigraphic record well documented for most Stephanian basins. The deposits and their floral records allow regional correlations between the different basins, and the succession in the St-Etienne coalfield (France) has been used as a nominal stratotype for the Stephanian, although good correlations with the internationally recognised marine stratotypes are still missing for this time interval. Volcanic materials (ash layers and lavas) often occur in these basins and can be dated by radiometric techniques. Their absolute dating is thus expected to provide new control points to help refine comparison between stratigraphic sections, particularly between marine and terrestrial successions. Most of the available radiometric dating on the Middle and Upper Carboniferous continental successions (Westphalian/Stephanian) outcropping in the Variscan Belt of Europe are from foreland basins (see Menning et al., 2001). Only little attention has been paid to basins outcropping in the internal zones of the belt, particularly in the French Massif Central. In this contribution, we present recent radiometric dating carried out on a series of volcanic ash layers sampled in different Upper Stephanian basins from the French Massif Central (Figure 1). This work has been undertaken in the course of the BRGM GéoFrance 3D program (Bouchot et al., 1997).

Background

Volcanic intercalations are common in these basins and occur as thin (10 to 60 cm) irregular ash layers which are considered to be products of an explosive, rhyolitic to dacitic, volcanism. In the field, they can be easily recognized because of their striking colours (including various shades of yellow, reddish and pale green) and soapy texture. All studied volcanic ash layers consist of an argillaceous matrix and contain phenocrysts of quartz, biotite, feldspar, and various amounts of zircon and apatite. The occurrence of accretionary lappillis in several tuffs suggests that some of them were transported as eruption clouds and were subsequently deposited as fallout particles in the basins. U-Pb zircon dating was achieved on volcanic ash layers interbedded in six basins located in the Southern (Alès, Bertholène, Graissessac, Jaujac et Roujan/Néffiès) and Northwestern (Bosmoreau) part of the French Massif Central (Figure 1). Zircons are generally translucent, colourless with euhedral shapes and sharp terminations suggesting short sedimentary transport. Scanning electron microscope observation of polished sections reveals typical magmatic/volcanic features such as oscillatory zoning, gas tubes or growth hiatuses (Figure 2A and B). All basins contain floral records indicating an Upper Stephanian age (see Becq-Giraudon et al., 1995), thus giving the opportunity for a combined biostratigraphic and radiometric age control on sedimentation.

Analytical Techniques

Bentonite samples of ca. 15 to 25 kg were separated from the enclosing sediments. They were subsequently jaw-crushed and screened to < 500 ì m. Zircon concentrates were extracted by Wifley table, heavy liquids, and magnetic separation following standard techniques (e.g., Bosch et al., 1996). Zircons from the non-magnetic fraction, together with chips of standard zircon, were then mounted in epoxy resin and polished to approximately half their thickness to expose internal structure. SIMS U-Th-Pb analyses were performed on the CAMECA IMS 1270 ion microprobe at the CRPG Nancy (France) following the technique outlined by Deloule et al. (2001). K-Ar isotopic determinations were made at the CGS Strasbourg (France) following a procedure close to that reported by Bonhomme et al. (1975). K was measured by flame spectrophotometry with a global accuracy of ± 1.5 %, based on systematic controls of international standards. Ages were calculated at the 95% confidence level using the Isoplot program (Ludwig, 1999). Standard decay constants are those recommended by the IUGS Subcommission on Geochronology (Steiger and Jäger, 1977).

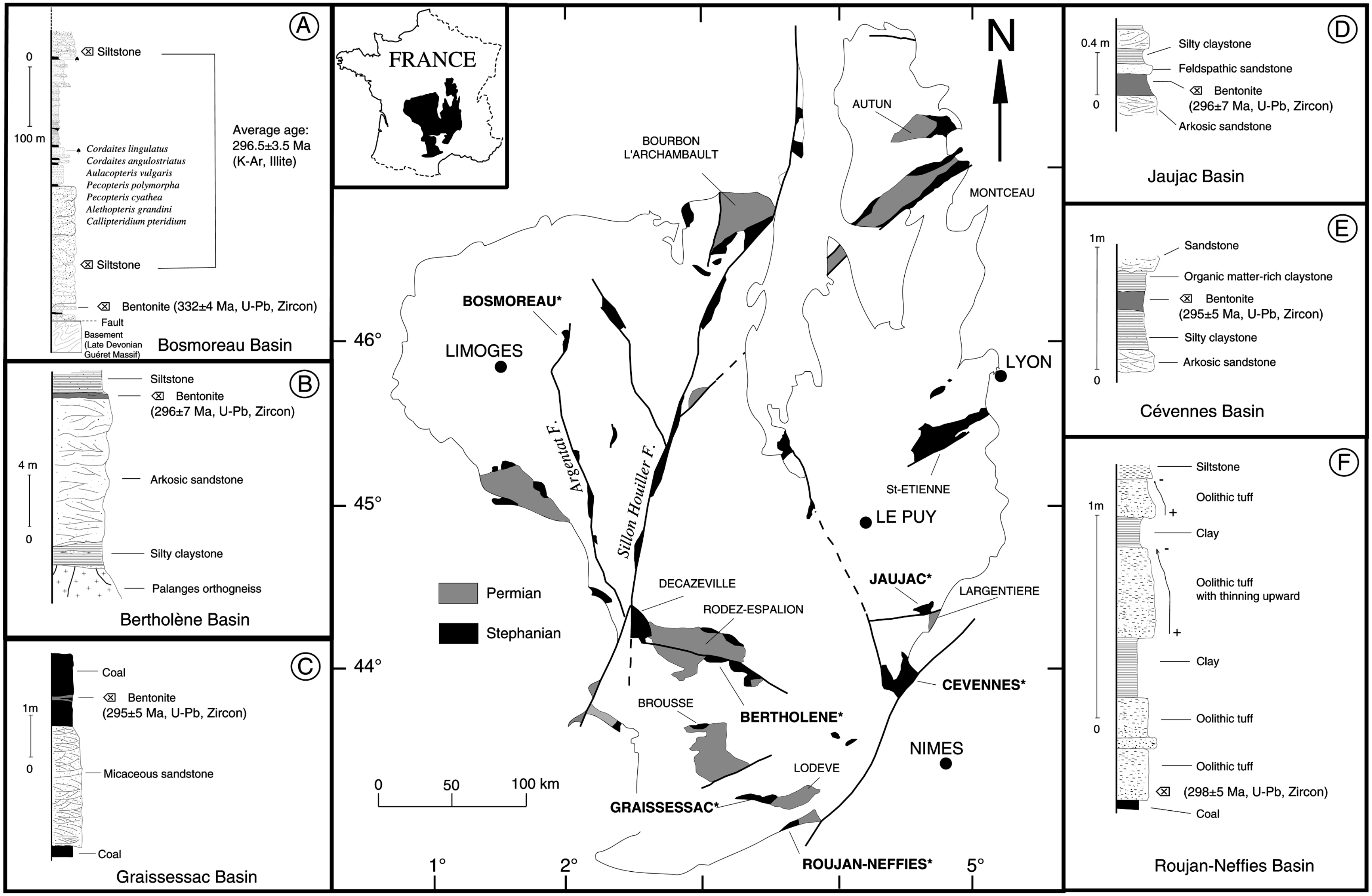

Figure 1: Distribution of the main Stephanian/Autunian basins of the French Massif Central (modified from Becq-Giraudon et al., 1996). Insets show lithostratigraphic columns of part of the sedimentary sequences accumulated in the Bosmoreau (A), Bertholene (B), Graissessac (C), Jaujac (D), Ales (E) and Roujan-Neffies (F) basins, with location of the studied bentonites samples (⌧).

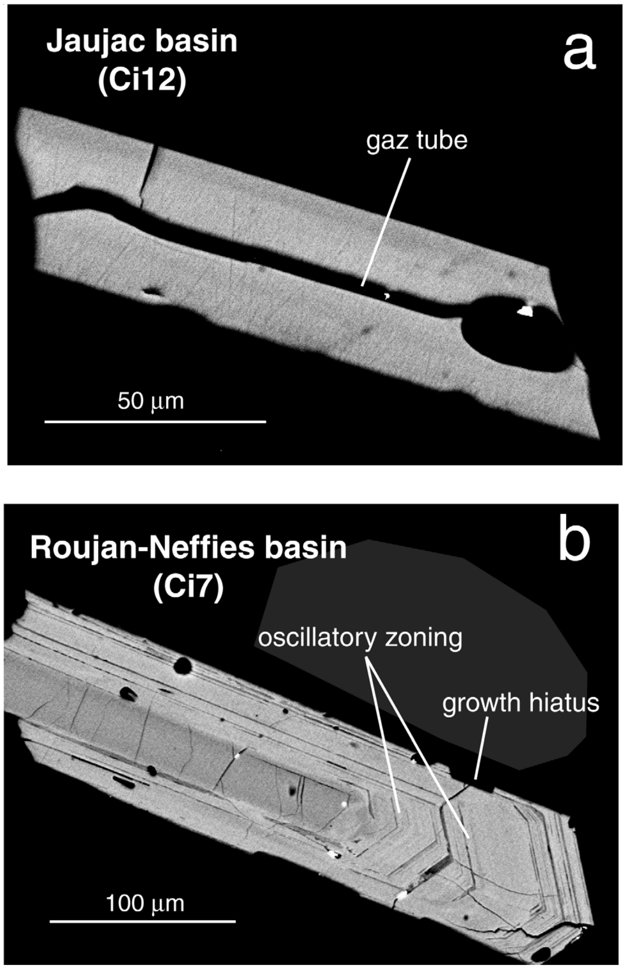

Figure 2: Example of SEM photomicrographs of volcanic zircons extracted from ash layers sampled in the studied basins. White ellipses show the approximate location of the area analyzed *in situ* by the IMS 1270 ion-probe.

Results

Concordant clusters of results of zircon U-Pb analyses from the five investigated volcanic tuffs (see Figure 1) fall within the age interval of 295-300 Ma, i.e., in the Gzhelian Stage of the Stephanian Series according to Odin (1994). Because ash clouds are rapidly deposited, they instantaneously date the sedimentation of adjacent strata. All five individual U-Pb ages are indistinguishable at the 2ó level, and it is considered that the time of eruption and sedimentation of the volcanic ash in the five basins is essentially coeval. Age bias due to reworking of older volcanoclastic material, or even to incorporation of detrital material, is unlikely given the zircon morphology (Figure 2) and occurrence of accretionary lapillis in some of the layers dated. The latter formed during the flight of the ash cloud, and are too fragile to be reworked or transported even over short distances. Moreover, the excellent consistency of the present data set argues against such an hypothesis. Although the error margins are too large to be used as precise markers in the Carboniferous time scale, these ages are consistent with the stratigraphic position of the volcanic layers dated. This is important to note, as some Stephanian basins in the FMC (Bruguier et al., 1998) and also within other parts of the Variscan Belt (Von Raumer, 1998) are clearly successors of older basins that indicate an earlier phase of extensional tectonics and basin development. All ion probe analyses have been combined (Figure 3) to give a weighted mean $^{206}Pb/^{238}U$ age of 297.9±2.1 Ma (95% confidence level) which is interpreted as bracketing the range of the Stephanian volcanic activity in the southern part of the FMC. Further studies should reveal whether this is real or rather an artifact due to the limited number of samples studied.

Radiometric dates are scarce for Stephanian occurrences in the French Massif Central, including the continental reference series of the St-Etienne Basin, and comparisons are thus limited. However, this 295-300 Ma time interval is in good agreement with K-Ar dating of clay particles from the Bosmoreau Basin in the north-western part of the FMC which gave a mean deposition age of 296.5±3.5 Ma (Bruguier et al., 2003) and also with muscovite and biotite $^{40}Ar/^{39}Ar$ ages (297±3 Ma) from the southern and northern part of the Montagne Noire area. The latter have been interpreted as marking movement along an active detachment (Maluski et al., 1991) and the contemporaneous development of the Graissessac Basin (see Figure 1). Lastly, the Upper Stephanian volcanic and basin-forming event in the FMC is also contemporaneous with volcanic events identified in other parts of the Variscan Belt which yield ages broadly ranging from 295 Ma to 300 Ma, although slightly older ages (300-305 Ma) have been also obtained (see Schaltegger and Corfu, 1995; Breitkreuz and Kennedy, 1999; Köninger et al., 2002). The period 295-300 Ma may thus be the climax of a short-lived pulse of explosive volcanism close to the Carboniferous-Permian boundary. This is taken as evidence for a synchronous basin-forming event occurring at an orogenic belt scale, at the end of the Carboniferous.

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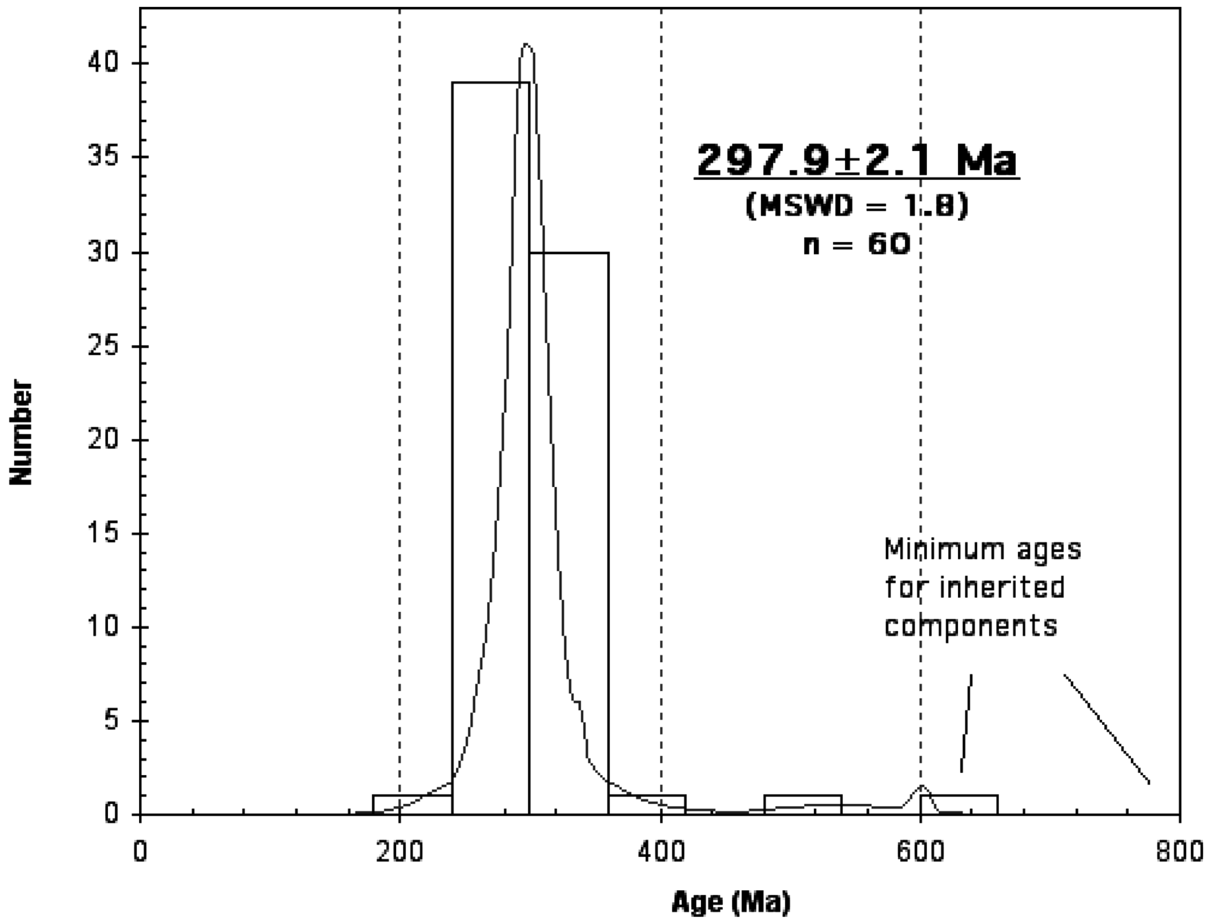

Figure 3: Frequency histogram showing the distribution of the $^{206}Pb/^{238}U$ ages of ion-probe zircon analyses from the investigated ash-fall tuffs.

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Carboniferous tetrapod footprint biostratigraphy and biochronology

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The fossil record of tetrapod footprints extends from the Upper Devonian to the Neogene. For this majority of the Phanerozoic, which encompasses the entire tetrapod body fossil record, at many places the only tetrapod fossils known are footprints. This means that footprints provide important data on vertebrate distribution in space and time. Furthermore, unlike invertebrate ichnologists, who view their trace fossils primarily as evidence of behavior, not necessarily of the presence of specific biological taxa, vertebrate ichnologists long ago decided to treat tetrapod footprints as proxies of biological taxa. Because of this, drawing inferences about tetrapod distribution in time and space is a significant goal of the study of tetrapod fossil footprints (e.g., Lockley, 1998). Biostratigraphic correlations and biochronological subdivisions based on tetrapod footprints (Haubold and Katzung, 1978 termed this "palichnostratigraphy") thus have been common, especially in the late Paleozoic and early Mesozoic. Here, I evaluate the utility of tetrapod fooprints in Carboniferous biostratigraphy and biochronology. My conclusion is largely negative, that tetrapod footprints are generally not very useful in Carboniferous biostratigraphic correlation and biochronological subdivision.

Carboniferous tetrapod footprints have a strictly Euramerican distribution (Fig. 1), as does the Carboniferous tetrapod body fossil record (with the exception of a recent discovery in Australia: Thulborn et al., 1996). The single biggest hindrance to a palichnostratigraphy of Carboniferous tetrapod footprints is the currently confused and confusing state of the ichnotaxonomy of Mississippian and Pennsylvanian tetrapod footprints. Matthew (1903a) last attempted a comprehensive revision(!), though Haubold (1970, 1971a) did clarify some of the ichnotaxonomy. My impression is that almost every article on Carboniferous tetrapod footprints published in the twentieth century created at least one new ichnospecies or ichnogenus, contributing to a multiplicity of names being applied to the same footprint morphologies. The need for vast taxonomic revision is obvious.

A good example is provided by the new ichnogenus *Puertollanopus*, recently named by Soler-Gijón and Moratalla (2001) from the Upper Pennsylvanian (Stephanian) of Spain. They based this ichnogenus on underprints of a quadruped with a pentadactyl pes and tetradactyl manus, of small size (pes length and width = 20-22 mm). A detailed diagnosis and lengthy comparison to other Carboniferous ichnogenera includes the claim that *Puertollanopus* differs from similar *Batrachichnus* by lacking the slender and elongated digits that supposedly characterize *Batrachichnus*. A comparison of *Puertollanopus* to the range of variation illustrated for *Batrachichnus* by Haubold et al. (1995, especially their figs. 1-2) suggests otherwise; *Puertollanopus* is a synonym of *Batrachichnus*.

Nevertheless, to revise Carboniferous tetrapod footprint ichnotaxonomy is beyond my scope here, though I conclude that three intervals of Carboniferous time (Fig. 2) can be discriminated using footprints: Mississippian, Early-Middle Pennsylvanian (approximately Westphalian) and Late Pennsylvanian (approximately Stephanian).

Hunt et al. (1995) and Cotton et al. (1995) provided useful reviews of the North American Carboniferous track record. The most extensive Carboniferous footprint record comes from Nova Scotia (Canada). Indeed, W. E. Logan first discovered Paleozoic tetrapod tracks in Nova Scotia in 1841. Charles Lyell published this record, proclaimed reptile tracks by Richard Owen, though they were later shown to be amphibian. Extensive and classic studies by Willliam Dawson (1844, 1845, 1863a, b, 1868, 1872, 1882, 1893, 1895) and George Matthew (1903a, b, c, 1904, 1905) followed, and the Nova Scotian track record is the most complete single stratigraphic succession of Carboniferous tracks known (Fig. 2).

In Nova Scotia, Mississippian tracks are from the Horton and Mabou groups (Fig. 2) and have been assigned to the ichnogenera *Hylopus*, *Megapezia*, *Palaeosauropus*, *Peratodactylopus* and *Baropezia* (Sarjeant and Mossman, 1978). Pennsylvanian tracks from the Cumberland and Pictou groups are assigned to the ichnogenera *Anthichnium*, *Asperipes*, *Barillopus*, *Baropezia, Cursipes, Dromillopus, Hylopus, ?Limnopus, Matthewichnus, Ornithoides, Orinthoidipus, Pseudobradypus, Quadropedia* and *Salichnium* (Sternberg, 1933; Sarjeant and Mossman, 1978; Mossman and Grantham, 1996, 2000). Red beds on nearby Prince Edward Island yield Early Permian tracks assigned to the ichnogenera *Amphisauropus, Gilmoreichnus* and *Ichniotherium* (Mossman and Place, 1989). Thus, in eastern Canada, a remarkable stratigraphic succession of Mississippian (Tournaisian and Namurian), Pennsylvanian (mostly Westphalian A and B) and Early Permian tracks is present. I regard this as the global standard (though not a complete one) for Carboniferous track succession (Fig. 2).

Records in the eastern United States are more scattered, less extensive and include: (1) in the Naragansett Basin of Rhode Island and Massachusetts, *Parvipes* from the Alleghanian Wamsutta Formation (Willard and Cleaves, 1930) and *Batrachichnus, Matthewichnus, Parvipes, Megapezia, Nanopus* and *Paleosauropus* from the Alleghanian Rhode Island Coal Measures (Woodworth, 1900; Lull, 1920; Willard and Cleaves, 1930); (2) in Pennsylvania, *Palaeosauropus* in the Mississippian (Chesterian) Mauch Chunk Group (Lea, 1852; Leidy, 1879; Barrell, 1907), *Anthracopus* in the Lower Pennsylvanian Pottsville Group (Leidy, 1879), *Limnopus* in the Missourian Casselman Formation of the Conemaugh Group (Baird, 1965) and *"Cheirotherium"* (invalid ichnogenus) in the Virgilian Monangahela Group (Moore, 1873); (3) in Ohio, *Megabaropus* and *Dromopus* from the Monangahela Formation (Carman, 1927; Baird, 1952; Patterson, 1971), *Pseudobradypus* from the Allegheny Formation (Carman, 1927), *Pseudobradypus* and *Megabaropus* from the Conemaugh Group (Mitchell, 1931, 1933), and *Limnopus* from the Missourian Cow Run Sandstone of the Conemaugh Group (Baird, 1952); (4) in Indiana, *Paleosauropus* from the Mississippian (Chesterian) Tar Springs Formation

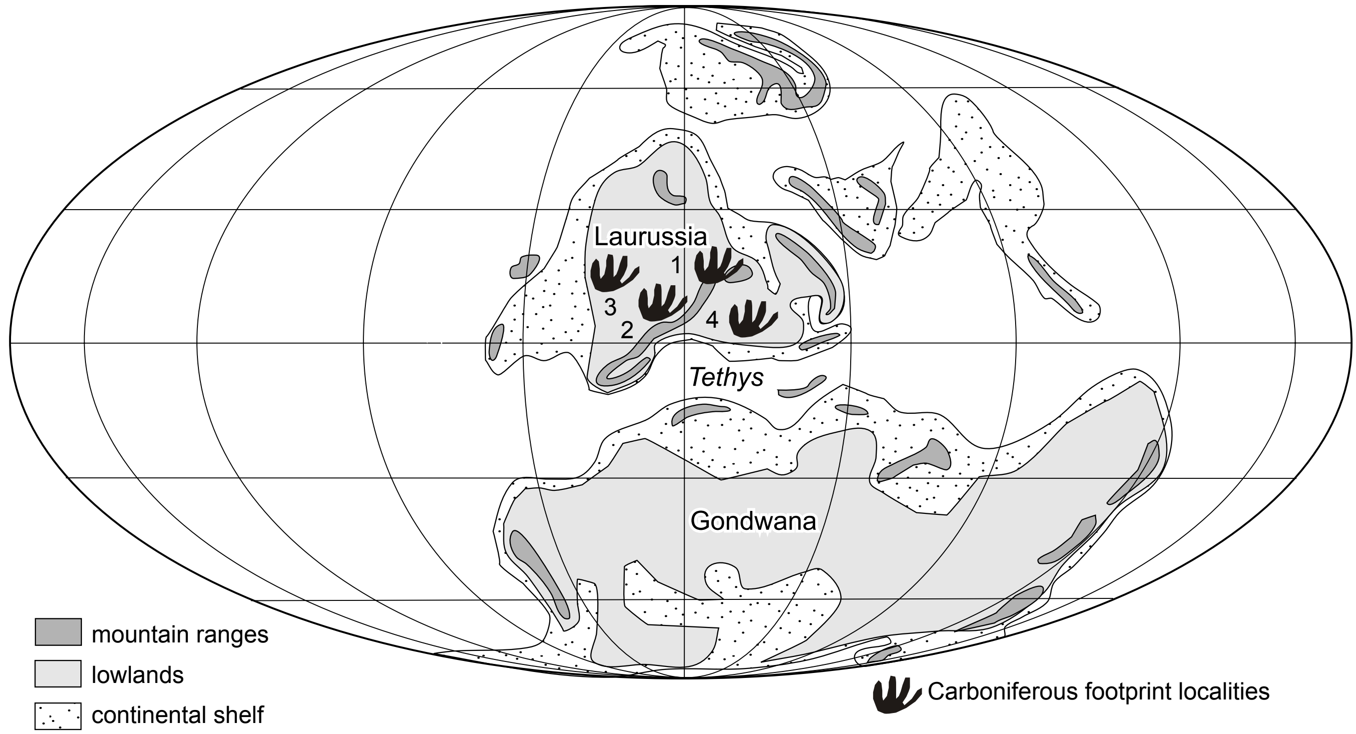

Figure 1. Distribution of principal Carboniferous tetrapod tracksites: 1, Nova Scotia, 2, eastern United States, 3, western United States, 4, western Europe. Base map after DiMichele and Hook (1992).

(Colbert and Schaeffer, 1947), and *Colletosaurus*, *Cincosaurus* and *Notalacerta* from various localities in Lower Pennsylvanian strata (Cox, 1874; Lane and Maples, 1990; Cotton et al., 1995; Monks, 2002); (5) in Virginia, tracks originally assigned to *Dromopus*, but later reassigned by Haubold (1971a) to *Asperipes*, from the Mississippian Hinton Formation (Branson, 1910); (6) in West Virginia, indeterminate tracks from the Mississippian Pocono Formation (Dunkle, 1948), *Limnopus* from the lower Conemaugh Group (Martino, 1991) and amphibian tracks from the Conemaugh and Monangahela groups (Jake and Blake, 1982; McClelland, 1988); (7) *Matthewichnus* from the Middle Pennsylvanian of Tennessee (Kohl and Bryan, 1994); (8) *Notalacerta* from the Lower Pennsylvanian of Kentucky (Chestnut et al., 1994); (9) *Cincosaurus* from the Lower Pennsylvanian of Georgia (Schneck and Fritz, 1985); and (10) in Alabama, several endemic ichnogenera as well as *Cincosaurus* and *Quadropedia* from the Lower Pennsylvanian Pottsville Formation (Jones, 1930; Aldrich and Jones, 1930), and an extensive footprint assemblage, including *Cincosaurus*, just being studied from Lower Pennsylvanian strata at the Union Chapel Mine in the Black Warrior Basin (Rindsberg et al., 2001).

Only scattered occurrences are known from the Carboniferous strata of the western United States: (1) "*Steganosauropus*" (probably *Anomalopus*: Lockley and Hunt, 1995) from the Pennsylvanian Tensleep Sandstone near Lander, Wyoming (Branson and Mehl, 1932); (2) amphibian tracks (some assigned to *Baropezia*) from the Upper Pennsylvanian Fountain, Minturn and Belden formations near Boulder and Dotsero, Colorado (Henderson, 1924; Toepelman and Roedeck, 1936; Houck and Lockley, 1986); (3) an assemblage from the Virgilian Wescogame Formation in the Grand Canyon of Arizona that includes *Batrachichnus, Anomalopus* and *Stenichnus* (Gilmore, 1927); (4) tracks from the Virgilian Howard Limestone in Kansas, including the type material of *Limnopus* and *Dromopus* (Mudge, 1874; Marsh, 1894; Baird, 1952; Schoewe, 1956) and tracks assigned to *Notalacerta* and *Megabaropus* from the Missourian Garnett quarry (Reisz, 1990); (5) in Oklahoma, *Oklahomaichnus* from the Pennsylvanian near Oklahoma City (Sarjeant, 1976) is not a tetrapod track (Lucas and Lerner, 2001), but Jillison (1917) illustrated amphibian tracks from Pennsylvanian strata near Pawhuska, and Lerner et al. (2002) reported *Notalacerta* and *Pseudobradypus* from Desmoinesian strata in eastern Oklahoma; and (6) in Missouri, tracks from the Missourian interval of the Kansas City Group include *Batrachichnus, Notalacerta* and *Cursipes* (Branson and Mehl, 1932).

In Europe, Carboniferous tetrapod footprints come principally from Germany, France and Great Britain, but there are also some records in Spain (Soler-Gijón and Moratalla, 2001), Italy (Mietto et al., 1985) and the Czech Republic (Turek, 1989). The oldest European Carboniferous tracks are from Northumberland in England in strata of Namurian (Late Mississippian) age (Barkas, 1878; Sarjeant, 1974; Scarboro and Tucker, 1995). The tracks Barkas illustrated are problematic, but Scarboro and Tucker (1995) documented unusually large (18 cm long) tracks of a temnospondyl amphibian.

Westphalian (approximately Early-Middle Pennsylvanian) sites are more common and are in Germany (especially in the Ruhr Basin and in Sachsen), France and the Czech Republic (e.g., Wolansky, 1952; Schmidt, 1956, 1963; Müller, 1962; Dollé et al., 1970; Haubold, 1970; Fichter, 1982; Milner, 1994). These tracksites contain many of the same ichnogenera as their North

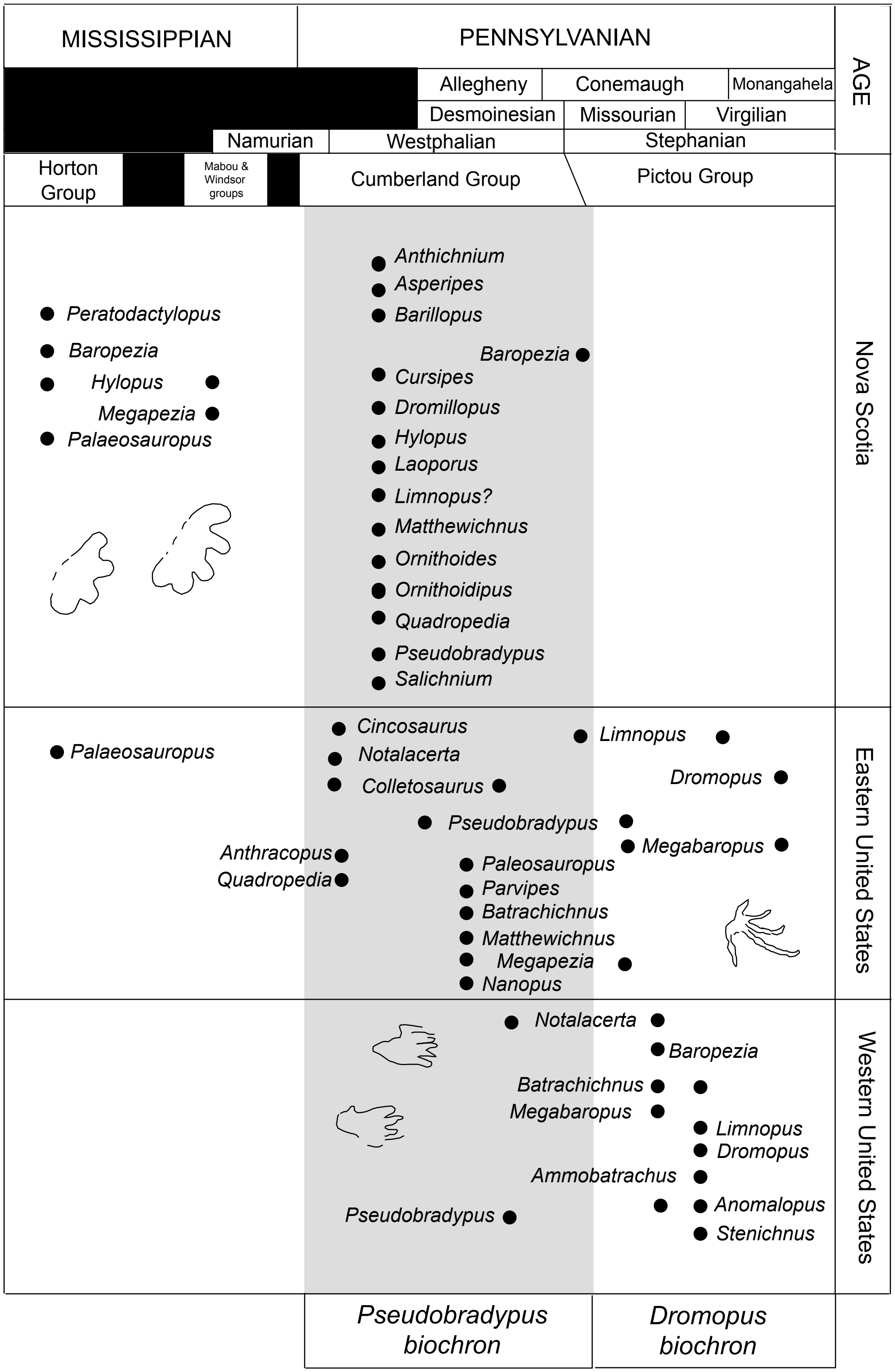

Figure 2. Temporal distribution of Carboniferous tetrapod footprint ichnogenera in North America (see text for sources). Section in Nova Scotia based on Calder (1998)

American correlatives (e.g., *Anthracopus, Limnopus, Paleosauropus, Pseudobradypus* and *Salichnium*) and thus show a mixture of temnospondyl tracks and captorhinomorph tracks. In Europe, as in North America, it is the abundance of captorhinomorph tracks that distinguishes the Westphalian sites from the Mississippian sites.

Younger, Stephanian (approximately Late Pennsylvanian) sites are in Germany, France, Italy, England and Spain (e.g., Langiaux, 1979, 1980, 1981; Langiaux and Sotty, 1975a,b, 1976, 1977; Haubold and Sarjeant, 1973; Gand, 1975; Mietto et al., 1985; Blieck et al., 1997; Soler-Gijón and Moratalla, 2001). These are broadly similar to the Westphalian assemblages, but also include the lowest occurrences of *Batrachichnus, Ichniotherium, Dromopus, Gilmoreichnus* and *Dimetropus*, ichnotaxa characteristic of the younger, Early Permian tetrapod ichnofauna.

Based on the above review, three intervals of Carboniferous time can be discriminated using tetrapod footprints:

1. The Mississippian track record (mostly known from North America) is temnospondyl dominated and has rare captorhinomorph tracks.

2. The Early-Middle Pennsylvanian (Westphalian) record shows a mixture of temnospondyl tracks (e.g., *Limnopus, Schmidtopus, Paleosauropus, Cursipes*) and captorhinomorph (e.g., *Pseudobradypus, Asperipes*) tracks. It is the abundance of the captorhinomorph tracks that distinguishes the Westphalian sites from the Mississippian sites, and I term this interval the *Pseudobradypus* biochron.

3. The Late Pennsylvanian track record includes the lowest occurrences of *Batrachichnus, Ichniotherium, Dromopus, Gilmoreichnus* and *Dimetropus*, ichnotaxa characteristic of the younger, Early Permian ichnofauna. This is the beginning of the *Dromopus* biochron, which continues through the Early Permian.

The use of fossil tetrapods (amphibians and reptiles) to subdivide Carboniferous time dates back to the late 1800s, when Marsh (1891, 1898) divided the North American Carboniferous into the "*Sauropus* beds" and "*Eosaurus* beds." He indicated that the former, based on a footprint ichnotaxon, is the time of the first amphibians, whereas the latter is the time of the first reptiles. This is one of the first explicit uses of tetrapod footprints in biostratigraphy, but unlike Carboniferous plant-based biostratigraphy, no tradition grew out of Marsh's work.

The tetrapod body-fossil record can be used to divide Carboniferous time into only four intervals (Lucas, 2001), largely because of the limited geographic distribution, low taxonomic diversity and inadequate sampling of Carboniferous tetrapod fossils (Carroll, 1979). In essence, these four tetrapod-based time intervals are global chronofaunas. They provide poor biochronological resolution and a limited basis for tetrapod-based correlation, but accurately map current understanding of the major phases in Carboniferous tetrapod evolution. The footprint record thus resolves Carboniferous time almost as well as the body fossil record, though both provide very poor temporal subdivision of the Carboniferous, which in marine rocks is divided into as many as seven epochs that encompass 25 stages (Rotai, 1979; Harland et al., 1990), though a globally applicable timescale may discriminate only about eight stages (e.g., Menning et al., 2000).

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Baltic Stratigraphic Association

6TH BALTIC STRATIGRAPHIC CONFERENCE

St. Petersburg, Russia, August 22-26 , 2005

Pre-registration

Please, fill in and return

BALTIC STRATIGRAPHIC ASSOCIATION
6th Baltic Stratigraphical Conference
St. Petersburg, Russia, August 22-26 , 2005

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Please check:
I plan to attend the conference: ☐ possibly ☐ probably ☐ most certainly

☐ I intend to present oral presentation
☐ I plan to present a poster
☐ I intend to submit an abstract entitled:
…………………………………..……………..…………………………………………………………………
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I plan to attend the field trip:

- the Cambrian – Ordovician yes ☐ no ☐
- the Devonian yes ☐ no ☐
- the Carboniferous yes ☐ no ☐
- the Quaternary yes ☐ no ☐

I need an official invitation:
yes ☐ no ☐

I intend to be accompanied by
yes ☐ no ☐

Your proposals and suggestions on sessions and topics of symposia are highly welcome.

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Baltic Stratigraphic Association

6TH BALTIC STRATIGRAPHIC CONFERENCE

St. Petersburg, Russia, August 22-26 , 2005

All colleagues are cordially invited to attend the 6th Baltic Stratigraphic Conference. The Conference will be held in St. Petersburg, August 22-26, 2005 at the All-Russia Geological Research Institute (VSEGEI) and St. Petersburg State University. The meeting will deal with aspects of stratigraphy in the Baltic Region and adjacent territories. The scientific sessions are planned for August 22-26. The suggested pre- and post-conference field trips are as following:

- to the Cambrian – Ordovician of the Leningrad District;
- to the Devonian of the Leningrad, Pskov and Novgorod districts;
- to the Carboniferous of the Leningrad and Novgorod districts;
- to the Quaternary of the Leningrad District.

The meeting will be extended, as necessary, in order to accomodate proposed field trips.

Participants are invited to submit abstracts for both oral and poster presentations; instructions will be sent in the first circular.

Organizing Committee

Conference Chairman:	Dr. Tatyana Koren' (VSEGEI)
Vice-Chairmen:	Dr. Oleg Petrov (VSEGEI)
	Dr. Igor Buldakov (St Petersburg University)
Secretary:	Dr. Andrey Zhuravlev (VSEGEI)
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	Dr. Alexander Ivanov (St Petersburg University)
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Please, fill in and return the pre-registration form (located on page 42) by e-mail no later than January 10, 2004.

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10th Coal Geology Conference

June 7-11, 2004
Faculty of Science, Charles University,
Prague, Czech Republic

For details contact:

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Main Topic: Reasonable utilization of coal reserves with regard to environment.
Other Topics: Geology and paleontology of coal-bearing strata, coal prospecting, exploration, evaluation and utilization of coal reserves, energy policy, coalbed methane, environmental impact of mining and combustion of coal.

Geo and sightseeing tours

Summer 2004

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“Yugyd Va” (means “ Clear Water” in the Komi language) - The first Russian National Park included among UNESCO Monuments of Natural Heritage.

Picturesque canyons of the Tschugor River, the so-called Upper, Middle, and Lower Gates, composed of Carboniferous and Permian limestones.

A variety of optional routes are available including floating down the Tschugor River along the Northern Ural ridge to its junction with Pechora.

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Ilych River area, Pechora - Ilych Biospheric Park.

Experience the unique nature of the Northern Urals, which feature Permian and Carboniferous exposures. Majestic weathered columns in the Man - Pupu - Ner ridge and other sightseeing destinations that are worth visiting.

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Upper Carboniferous - Lower Permian Kozhim Carbonate Buildup. An example of deposition in somewhat cooler environments than known analogues in the Southern Urals. For details and photographs see Wahlman, G.P. 2002. Upper Carboniferous - Lower Permian (Bashkirian - Kungurian) mounds and reefs. SEPM Special Publication 72, p. 271-338; and Wahlman, G.P., and Konovalova, M.V. 2002. Upper Carboniferous - Lower Permian Kozhim carbonate bank, Subpolar Pre-Ural Mts, northern Russia . SEPM Special Publication 74 (in press).

The build-up section is easily accessible by normal railway transport and is about 10 km from the station. The most favorable weather conditions in the area of the Northern and Subpolar Urals occur in late June, July, and August.

For details please e-mail: likon@online.ru, or write: M.V. Konovalova, Pushkin str. 6 –12, 169300 Ukhta, Russia.

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