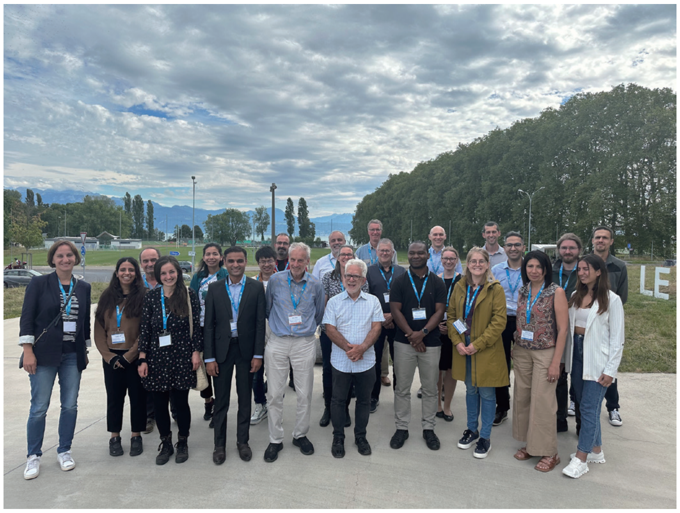
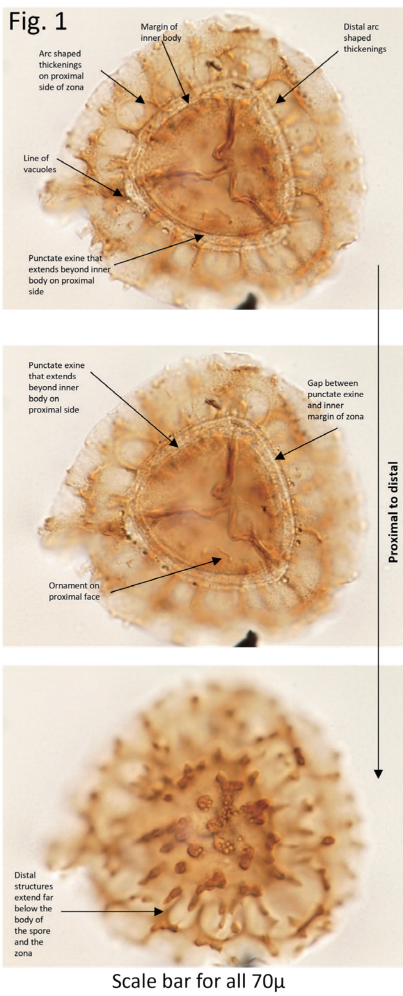
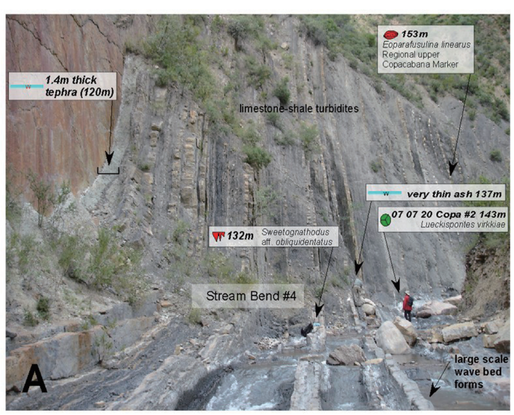
Permophiles

International Commission on Stratigraphy







Newsletter of the Subcommission on Permian Stratigraphy
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Fig. 1. Group photo of participants of conference held in Switzerland. Daley and Baud, this issue.
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Notes from the SPS secretary
Yichun Zhang

Introductions and thanks

At the beginning of December, 2023, I was a little bit worried about the limited numbers of submissions for this issue. However, just at the end of 2023 and the first week of 2024, my doubt cleared up because we received many submissions. I am impressed by the enthusiasm of our Permian colleagues. They always keep active and dynamic in many Permian topics. This is the motivation for me to edit each issue of *Permophiles*.

From this issue, we have a new Newsletter Editor Elizabeth Weldon, and I thank her for her good editorial work. Also, I would like to thanks SPS Chair Lucia Angiolini and vice-Chair Mike Stephenson for their great efforts in editing this issue of *Permophiles*.

This issue of *Permophiles* contains diverse articles. There are many discussions about Permian GSSPs, such as the base-Roadian, base-Wordian and base-Sakmarian. There are also many different opinions on some key scientific problems, and *Permophiles* is a good platform for free discussions as these contrasting ideas will be significant for guiding Permian studies. Thanks all contributors of this issue: Charles M. Henderson, Spencer G.Lucas, Michael H. Stephenson, Shuzhong Shen, Holger C. Forke, Mercedes di Pasquo and co-authors, Lorenzo Marchetti, Vladimir I. Davydov, Michael Buchwitz and co-authors, Per Michaelsen, Karsten M. Sttoretvedt, Allison C. Daley, Aymon Baud, Shuhan Zhang and Juan Moisés Casas-Peña.

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This issue starts with the 12th Harangue by Charles M. Henderson. His concern in this harangue is “how precise can we expect to correlate the designated point of a GSSP”. A balance between FADs of a designated species and a precisely dated ash bed is anticipated.

In the following article, Charles M. Henderson and Shuzhong Shen have a call to develop two new working groups, respectively base-Roadian and base-Wordian working groups, to resolve the problems of both GSSPs.

Charles M. Henderson reported recent works at the Rockland Section in Nevada, including conodonts and geochemistry.

Spencer G. Lucas commented on the problems of the GSSPs of Guadalupian stages in the Texas. He discussed the problems of using only conodonts in defining the Permian GSSPs. However, in the following article by Charles M. Henderson, the origin of Permian GSSPs was historically reviewed and he suggests that biologic markers (FAD of a specific species) are still workable in defining a GSSP that will allow global correlations.

Holger C. Forke provided a detailed review of complex Permian formations in the Carnic Alps. The fusulinids provided an age constraint for the Grenzland, Zweikofel/Zottachkopf and Trogkofel formations.

Michael H. Stephenson introduced the application of light microscopy of well-preserved, and particularly of broken specimens in studying the internal structure and affinities of spores.

Mercedes di Pasquo and co-authors reported their recent field work in the Apillapampa section in Bolivia and introduced the historical geological and paleontological work in the section. They highlighted the significance of potential palynomorphs as bridge-taxa between different continents.

Lorenzo Marchetti introduced the tetrapod footprint, tetrapod skeleton, insect association and conchostracan association from the Tambach Formation in Bromacker locality in central Germany and assigned a Sakmarian age for the Tambach Formation. In his second contribution, he reviewed the global effects of the Artinskian Warming Event.

Vladimir I. Davydov pointed out that a crisis is now occurring with respect to global Permian correlation. He highlighted that fusulinids and high-resolution dating work will be very important in Asselian to Artinskian correlations. The discrepancies between fusulinids and conodonts biochronology will be ultimately resolved by independent methods such as radioisotopic dates.

Michael Buchwitz and co-authors reported their fieldwork in Wolferode, central Germany, where diverse ichnofossil associations has been excavated from the outcrop.

Per Michaelsen and Karsten M. Sttoretvedt reported the Permian sequences in the central and southern Mongolia. The strata across the Permian-Triassic boundary were controlled by the sea level changes and record significant information about the collapse of peat mire ecosystem.

Allison C. Daley and Aymon Baud reported the conference at the University of Lausanne, Switzerland and post-conference excursions in Saint-Triphon and Bex areas.

Finally, extended abstracts were provided about two projects funded by SPS. Shuhan Zhang’s project aimed to integrate terrestrial and marine Permian stratigraphic data to provide more correlation markers with higher temporal resolutions, based on big data in OneStratigraphy and Geobiodiversity databases. Juan Moisés Casas-Peña’s project was about the provenance of the Permian turbiditic rocks of the Tuzancoa Formation in Mexico.

Future issues of Permophiles

The next issue of *Permophiles* will be the 77th issue. We welcome contributions related to Permian studies around the world. So, I kindly invite our colleagues to contribute harangues, papers, reports, comments and communications.

The deadline for submission to Issue 77 is 31 July 2024. Manuscripts and figures can be submitted via email address (yczhang@nigpas.ac.cn) as attachment.

To format the manuscript, please follow the TEMPLATE on SPS website.

Notes from the SPS Chair
Lucia Angiolini

We have finished just in time another issue of *Permophiles*, which required some additional editorial work because of the numerous and very interesting contributions we received.

This issue, more than ever, is what a newsletter of a Subcommission should be: a forum of discussion and a platform where new ideas and research topics are presented, besides of course the place to submit reports of meetings and synthetic results on Permian research. This outstanding issue is the result of the very interesting contributions by SPS voting and corresponding members and of the great editorial work of Yichun Zhang and our new Newsletter Editor Elizabeth Weldon. Also, I would like to thank Mike Stephenson for his great help to review the issue.

As usual, the first issue of the year contains the Annual Report which succinctly summarizes the results of SPS. I would like to draw your attention on the SPS Business Meeting and session organized during STRATI 2023, at Lille, France, 11th-13th July 2023; on the published proposal and redefinition of GSSPs and SABS (base Artinskian and base Wuchiapingian); on the two webinars permanently available to the Permian Community (https://permian.stratigraphy.org/interest); and on the selection of four new voting members (Neil Griffis, USA; Hana Jurikova, United Kingdom; Lorenzo Marchetti, Germany; Michael Read, USA).

As announced in December 2023, two research projects on Permian topics by young SPS corresponding members were funded by SPS: the abstracts of the projects are presented in this issue of *Permophiles*.

A new working group was established, the Kungurian-base GSSP Working Group, as completing the Permian Time Scale is our main goal for the next year.

However, as outlined in the webinar of October 24, 2023 “Progress, problems and perspectives for the base-Roadian and base-Wordian GSSPs” by Shuzhong Shen and Charles Henderson and in some of the contributions in this issue of *Permophiles*, we also have to focus our attention on the revision of the Guadalupian GSSPs.

The Guadalupian GSSPs (base Roadian at Stratotype Canyon, base Wordian at Getaway Ledge at Guadalupe Pass, and base Capitanian at Nipple Hill, SE Guadalupe Mountains, all in Texas) were briefly described and proposed by Glenister et al. (1999) in *Permophiles* 34: 3-11, the SPS vote was recorded in *Permophiles* 35 (1999; p. 4), and the proposals were ratified by ICS and IUGS in 2001.

Subsequent research mainly led by Shuzhong Shen and Charles Henderson resulted in the publication of the description of the base Capitanian GSSP (Shen et al. 2022, Episodes 45/3: 309-331), but revealed several problems for both the base Roadian and the base Wordian GSSPs, as summarized below:

-Base Roadian GSSP: the FO of the primary marker to correlate the boundary (the conodont *Jinogondolella nankingensis*) was recovered 6.1 metres above the golden spike. Additional correlation tools include detailed sequence stratigraphic interpretations including high frequency sequences. There are no additional biotic stratigraphic markers for correlation, but ammonoids and fusulinids have been used for regional correlation. Finally, the section is excellent and continuous and protected within a national park.

-Base Wordian GSSP: the conodont marker to correlate the boundary (*J. aserrata*) has not been found in the bed marked by the golden spike, but it first occurs (depending on interpretation) 5.4 metres below (as *J. aserrata* Morphotype B), or abundantly (as Morphotype A) at the base of a 12 m-thick limestone section. However, the base of this 12 m-thick limestone unit sits sharply above an unfossiliferous sandstone, which makes the establishment of the FO of the species impossible. The original section was on private land and it was moved into the national park in the proposal primarily based on lithostratigraphic correlation. There is no other biotic stratigraphic marker, but the stratigraphic units have been correlated with detailed sequence stratigraphy. The section is thus arguably unworkable.

To discuss those problems, on 21 December 2023 the SPS voting members met on zoom. Eighteen voting members out of 19 participated in the meeting. All voting members expressed their opinion and unanimously reached the conclusion that the base-Wordian should be redefined.

As there was a strong demand for it to be changed and there were grounds for revision after more than ten years (Remane et al. 1996, Episodes 19/3: 77-81), I informed ICS of the decision of SPS voting members to revise the base Wordian GSSP, and, on 8 January 2024, I obtained full approval from the ICS to move ahead.

The call for a base Wordian GSSP Working Group is presented in this issue by Henderson and Shen.

During the 21 December 2023 SPS voting members meeting, opinions varied about the Roadian: some members considering sufficient a detailed description of the GSSP for the sake of stability, others instead suggesting to move the boundary slightly higher in the section. For the moment the decision is to create a second Working Group on the base Roadian (see the call for a base Roadian GSSP Working Group presented in this issue by Henderson and Shen) to investigate different possibilities and report to SPS voting members.

In conclusion, as clearly shown by the contributions in this issue of *Permophiles*, there is a lot to do for the Permian, a huge amount of work that can be summarized in three words: complete, redefine, correlate.

I am confident that many of the contributions contained in this issue will stimulate replies, arguments and dialogues which will be published in the August issue of the Newsletter.

Please, read *Permophiles*, contribute to the discussion and send your ideas and proposals!

SUBCOMMISSION ON PERMIAN STRATIGRAPHY ANNUAL REPORT 2023

1.TITLE OF CONSTITUENT BODY and NAME OF REPORTER

International Subcommission on Permian Stratigraphy (SPS)

Submitted by: Lucia Angiolini, SPS Chair

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2.OVERALL OBJECTIVES, AND FIT WITHIN IUGS SCIENCE POLICY

Subcommission Objectives: The Subcommission’s primary objective is to define the series and stages of the Permian by means of internationally agreed GSSPs and establish a high-resolution temporal framework based on multidisciplinary (biostratigraphical, geochronologic, chemostratigraphical, magnetostratigraphical etc.) approaches, and to provide the international forum for scientific discussion and interchange on all aspects of the Permian, but specifically on refined intercontinental and regional correlations.

Fit within IUGS Science Policy: The objectives of the Subcommission involve two main aspects of IUGS policy: 1) The development of an internationally agreed chronostratigraphic scale with units defined by GSSPs where appropriate and related to a hierarchy of units to maximize relative time resolution within the Permian System; and 2) the establishment of framework and systems to encourage international collaboration in understanding the evolution of the Earth and life during the Permian Period.

3. ORGANISATION - interface with other international projects / groups

3a. Officers for 2020-2024 period:

Prof. Lucia Angiolini (SPS Chair)

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Prof. Michael H. Stephenson (SPS Vice-chair)

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Prof. Yichun Zhang (SPS Secretary)

State Key laboratory of Palaeobiology and Stratigraphy. Nanjing Institute of Geology and Palaeontology, 39 East Beijing Road, Nanjing, Jiangsu 210008, P.R. China, E-mail: yczhang@nigpas.ac.cn

4. EXTENT OF NATIONAL/REGIONAL/GLOBAL SUPPORT FROM SOURCES OTHER THAN IUGS

Shuzhong Shen and Michael Stephenson are investigating the possibility of support for SPS through the Deep-time Digital Earth (DDE) Big Science Program of IUGS focused on informatics support for biostratigraphic data management and palaeogeographic reconstructions.

5. CHIEF ACCOMPLISHMENTS IN 2023 (including any relevant publications arising from ICS working groups)

• The redefinition the Global Stratotype Section and Point (GSSP) for the base of the Wuchiapingian Stage (and Lopingian Series) was ratified by the IUGS Executive Committee on 24 July 2023.

• A Standard Auxiliary Boundary Stratotype (SABS) for the base of the Wuchiapingian Stage at the Fengshan Section, China, was approved by SPS on 16 April 2023.

• The paper "Proposal for the Global Stratotype Section and Point (GSSP) for the base-Artinskian Stage (Lower Permian)" by Chernykh et al. was published online in Episodes, June 15, 2023.

• The paper "Redefinition of the Global Stratotype Section and Point (GSSP) and new Standard Auxiliary Boundary Stratotype (SABS) for the base of Wuchiapingian Stage (Lopingian Series, Permian) in South China" by Shen et al. was published online in Episodes, November 1, 2023.

• Four new voting members were selected based on their extensive research in Permian stratigraphy (Neil Griffis, USA; Hana Jurikova, United Kingdom; Lorenzo Marchetti, Germany; Michael Read, USA). A Newsletter Editor has been invited (Elizabeth Weldon, Australia).

• A new Working Group was organized: Kungurian-base GSSP Working Group.

• The Permian Time Scale was kept updated https://permian.stratigraphy.org/gssps, the SPS website was kept updated, and two issues of *Permophiles* were published (SPS Newsletters *Permophiles* 74 and 75, the latter a special issue with "Permian Perspectives").

• Two webinars were organized, one on The IUGS Deep-time Digital Earth Program by Stephenson and one on Progress, problems and perspectives for the base-Roadian and base-Wordian GSSPs by Shen & Henderson (https://permian.stratigraphy.org/interest).

6. SUMMARY OF EXPENDITURE IN 2023

The amount received from ICS was spent for literature compilation, for the Standard Pro Annual ZOOM license for SPS, to support the participation to the STRATI 2023 Congress in Lille of two early career SPS corresponding members, and for funding two research projects of young SPS corresponding members on Permian topics.

The participation of Lucia Angiolini to STRATI 2023 was supported by the Organizing Committee of the STRATI 2023 Congress as she was invited to give a Plenary Talk; only subordinately SPS funds were used to support part of the field excursion expenses.

The field-trip to the Rockland section (Nevada), base Kungurian GSSP candidate, was postponed to 2024.

7. SUMMARY OF INCOME IN 2023

An amount of Euros 3262,56 euros was allocated from ICS in June 2023.

8. BUDGET REQUESTED FROM ICS IN 2024***

We apply for 4500 US$ from ICS for SPS activities in 2024. This will be mainly for the activities to establish the base-Kungurian GSSP at Rockland, Nevada and to organize a field trip in the area,

9. WORK PLAN, CRITICAL MILESTONES, ANTICIPATED RESULTS AND COMMUNICATIONS TO BE ACHIEVED NEXT YEAR:

• We plan to have the proposal of the base Kungurian GSSP published in *Permophiles* and voted by SPS voting members.

• We plan to start the revision of the Guadalupian base Roadian and base Wordian GSSPs.

• We plan to organize several webinars.

• We plan to support the activity of the working groups.

• We plan to renew the composition of the voting members bringing in more younger members of the Permian community.

• We plan to publish two *Permophiles* issues.

10. KEY OBJECTIVES AND WORK PLAN FOR THE PERIOD 2020-2024

• Establish the Artinskian and Kungurian GSSPs.

• Revise the Permian timescale where it needs to be improved (Guadalupian stages, replacement GSSP section of the base-Lopingian).

• Establish a robust palaeogeographic framework for the Permian and focus on N-S correlations.

• Propose DDE-sponsored informatics support for biostratigraphic data management and palaeogeographic reconstructions.

• Organize webinars to increase the size, diversity and international coverage of the Permian Community.

• Publish at least two *Permophiles* issues each year.

APPENDIX [Names and Addresses of Current Officers and Voting Members)

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Working group leaders

1) Kungurian-base GSSP Working Group; Chair: Charles Henderson.

2) Correlation between marine and continental Carboniferous-Permian Transition Working Group; Chair: Joerg Schneider.

3) Gondwana to Euramerica correlations Working Group; Chair: Mike Stephenson.

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Henderson's Harangue #12

Charles M. Henderson
Department of Earth, Energy, and Environment, University of Calgary, Calgary, Alberta, Canada T2N 1N4

On the twelfth day of Christmas my true love gave to me….a reasonably precise GSSP

As an attempt to stimulate debate or perhaps simply because something smells fishy, I deliver my twelfth harangue. In Italian, it would be "L' arringa di Henderson" (the double "r" is important).

In this issue of *Permophiles* there is a call for three GSSP working groups. The progress report for the base-Kungurian, as well as the call to develop new working groups to investigate the base-Roadian and base-Wordian GSSP all ask for researcher contributions. The decision was made during a SPS voting members meeting on zoom four days before Christmas on Dec 21st. This was a very good meeting and I was especially impressed by the insightful comments and questions by some of the newest and youngest members. As one of the oldest and most senior members it means I can confidently step aside in the near future. The meeting decision to strike new working groups was a good decision, but I am concerned about some of the expectations, which is the subject of this short harangue. You will get a sense of my concerns in my note in reply to the article by Spencer Lucas in this issue of *Permophiles*; he considers the Guadalupian chronostratigraphy to be unworkable. In contrast, I recognize it to be very workable as I emphasized in my SPS zoom seminar on Oct 24, 2023 with Shuzhong Shen. In answer to a question asking about expected precision, Spencer suggested he wanted "January 1st". Finding January 1st 274 million years ago is impossible – Spencer was really saying he wants the GSSP to be very precise. So the real question is "how precise can we expect to correlate the designated point of a GSSP"?

It has been suggested we should abandon the use of species FADs to mark a boundary and perhaps use a precisely dated ash bed. Recent precision on Guadalupian ages range from +/- 0.078 to 0.16 Myrs. Therefore the expected precision on a point marked by a 274 Ma ash bed (if there is one) is roughly 274.00 +/- 0.100 Ma. This means that we have roughly a 200,000 year interval in which to attempt to correlate a magnetic reversal or a carbon isotopic excursion (assuming they are not affected by diagenesis) or possibly the first occurrence of a taxon in a section that lacks volcanic ash beds – in my experience outside of South China many sections lack such deposits as they are distant from a volcanic arc. In this case the ash bed is a point, but we are precise if we can correlate within that 200 Kyr interval. I am also concerned that there seems to be a rule on the ICS website (stratigraphy.org/gssps/) that says "the section in which the marker appears SHOULD have layers containing minerals that can be radiometrically dated". To my knowledge, no other document like the International Stratigraphic Guide makes such a claim. The word "should" means it is not absolutely required, but in practice it would be considered a strike against a section, which would preclude many sections in the world from consideration. The Rockland section being developed for the base-Kungurian GSSP lacks ash beds. The Russian section it is replacing (Mechetlino) has “ash beds”, but there are no in-situ zircons, only old reworked zircons.

I am not objecting to an ash bed possibly becoming a GSSP marker – an eruption or series of eruptions along a volcanic arc would seem to be a natural event comparable to the evolution of a new biotic species. I think the FAD of a species is used extensively because the rock record provides many fossiliferous successions and because that evolutionary event is unique. Many other signals are binary representing normal or reversed polarity or positive or negative isotopic excursions. Most ash beds look identical in the field and are only distinguished using expensive instrumentation and analyses. However, it is not my intent to debate the relative merits of different markers – all should be explored if possible. My real intent is to ask a serious question and I would welcome comments from others. The question is this. How precisely do you expect to correlate a GSSP in sections with real rocks (not imaginary simulations)?

A GSSP is absolutely precise at the designated section since it is a point. But the correlation precision will come down to the resolution of the method and the precision of the measurements. The precision will come down to the number of samples, how quickly environments were shifting in that section, the expertise of the paleontologist, the repeatability of mass spectrometer analytic results, etc. It is not an easy equation although I am sure there are some that could come close. I suggested in my Oct 24 seminar that maybe we can expect +/- 250 Kyrs. Maybe I was pessimistic, maybe it should be +/- 200 Kyrs making the interval the equivalent of one long eccentricity cycle, which seem to be very common in the rock record. If it was half a cycle (+/- 100 Kyrs) then it would be the same as many (some are more precise) radiometric dates. Again, what level of precision do you expect when you correlate the base of the Roadian or any other stage?

Finally, we must consider these questions as we develop the base-Kungurian GSSP and the new revisions to the Roadian and Wordian. Maybe we already have reasonably precise GSSPs.

Call to develop two new working groups: the base-Roadian GSSP Working Group and the base-Wordian GSSP Working Group

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On October 24th 2023 we gave a combined zoom presentation on base-Roadian and base-Wordian GSSP progress, problems, and perspectives. This talk was recorded and can be found on the SPS website. In addition, different perspectives on these GSSPs are provided by Spencer Lucas and Charles Henderson in this issue of *Permophiles* (#76). Furthermore, on December 21st 2023, SPS voting members (18 of 19) met on zoom to discuss about the re-definition process for the base-Roadian and base-Wordian GSSPs. All voting members expressed their opinions on the two GSSPs. For the Wordian, there was a unanimous opinion that the base-Wordian should be redefined. For the Roadian there were mixed opinions that the boundary may be sufficient for the sake of stability or possibly revised slightly higher in the stratotype section. It was decided that two new working groups be established to investigate the different possibilities and report back to SPS voting members. This note is to ask Permian workers to volunteer for these working groups by contacting Charles Henderson and Shuzhong Shen by email. We will be contacting some people and the final composition of the working groups will be established by the chairs. The working group composition and progress will be reported in *Permophiles* #77.

Base Roadian GSSP Working Group:
Chair: Charles Henderson; cmhender@ucalgary.ca
Vice Chair: Shuzhong Shen; szshen@nju.edu.cn

Base Wordian GSSP Working Group:
Chair: Shuzhong Shen
Vice Chair: Charles Henderson

Base-Kungurian GSSP Working Group Progress

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Introduction

I announced a new working group in *Permophiles* 75 (p.8) that is tasked with preparing a GSSP proposal for the base Kungurian at the Rockland Section in Nevada. The current members include myself, Lucia Angiolini, Benoit Beauchamp, Luke Bratton, Daniel Calvo Gonzalez, Mike Read, Kate Tierney, Tamra Schiappa, Walt Snyder, and Dongxun Yuan. If there are others that wish to join this working group please contact me by email.

Progress

Considerable progress has been made on strontium isotopes. Kate Tierney has provided additional results from samples originally collected for her PhD. Luke Bratton has recently completed Sr isotopic analysis from a set of conodonts from the Rockland section that range in age from Sakmarian to mid-Kungurian. We have adjusted the ages of many of the samples used by McArthur (2020) to develop the GTS 2020 Strontium curve as a means to test the curve. Ages as determined from recent biostratigraphic correlation from key sections like Tieqiao in South China and Rockland Section in Nevada have been adjusted. Results will be provided in *Permophiles* 77.

The conodont sampling and preparation is complete and some new SEM images will be made later this winter. It was determined that new samples will need to be collected for fusulinids and possibly brachiopods. It is important that additional fossil groups are documented to assist correlation.

Plans

Another field excursion to the site is now in the planning stages for approximately May 13-20, 2024. Currently, Lucia Angiolini, myself, and Mike Read, who will collect fusulinid samples, are confirmed. We may also visit the Carlin Canyon site that has been mentioned in recent issues of *Permophiles*. These sites are protected and freely accessible on Bureau of Land Management (BLM) forestry land. The Working Group will prepare a preliminary draft of a GSSP proposal for *Permophiles* 77.

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The Permian Guadalupian stages: how politics and conodonts produced an unworkable chronostratigraphy

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The Permian chronostratigraphic scale was originally created over the course of about a century, from the 1880s to 1980s, based on ammonoid and fusulinid biostratigraphy (Karpinsky, 1889; Furnish, 1973; Douglass, 1977; Lucas and Shen, 2018). Thus, all of the Permian stages were originally defined by the stratigraphic distributions of ammonoids and/or fusulinids. However, in the 1990s a wholesale shift to using conodont biostratigraphy to define Permian chronostratigraphic units began under the direction of the Subcommission on Permian Stratigraphy (SPS). Among the first products of this conodont-based chronostratigraphy were the GSSPs of the bases of the three stages of the Guadalupian Series, the Roadian, Wordian and Capitanian (Fig. 1), three stages that were originally defined based on ammonoids (Miller and Furnish, 1940; Furnish, 1973). Proposed by Glenister et al. (1999), these Guadalupian GSSPs with conodont biotic events as their primary signals met rapid approval by the SPS and International Commission on Stratigraphy (ICS) (Wardlaw, 2001). The fully ratified GSSPs are located in the Guadalupe Mountains National Park in West Texas, USA (Henderson et al., 2020). However, the taxonomy and stratigraphic ranges of the conodonts used as primary signals of the GSSPs were never fully published. Indeed, the standard article(s) to propose the GSSPs never appeared in Episodes.

In 2015-2019, a research group led by Shuzhong Shen re-evaluated the GSSPs of the three Guadalupian stages and found many problems, recently detailed by Shen et al. (2020, 2022), Yuan et al. (2021), Lucas (2023) and Shen (2023):

1. The LO of serrated gondolellids (i. e., *Jinogondolella nankingensis*) was considered to be the primary signal of the base of the Roadian Stage (and of the Guadalupian Series), but such conodonts have been found about 100 m below the level of the base Roadian GSSP at Stratotype Canyon (Shen et al., 2020)

2. The primary signal of the base of the Wordian is supposed to be the LO (lowest occurrence) of *Jinogondolella aserrata*, but conodonts of that species were not recovered by extensive sampling of the GSSP level (Yuan et al., 2021). Instead, the LO of *J. aserrata* at the GSSP is stratigraphically well below the GSSP level, and Yuan et al. (2021) recognized two morphotypes of *J. aserrata*. Furthermore, those two morphotypes have different LOs. Clearly, the taxonomy of *J. aserrata* is now unclear, as is its stratigraphic range relevant to GSSP definition. Yuan et al. (2021) concluded that a replacement GSSP for the base of the Wordian is needed.

3. The base Capitanian GSSP at Nipple Hill only preserves about 5 m of Capitanian strata above the GSSP level (e. g. Henderson et al., 2020). Therefore, Shen et al. (2022) described what they call the Frijole reference section for the GSSP about 2.9 km to the west of Nipple Hill. At Nipple Hill, the LO of *Jinogondollela postserrata* (primary signal of the GSSP) is about 5 m above the base of the Pinery Member of the Bell Canyon

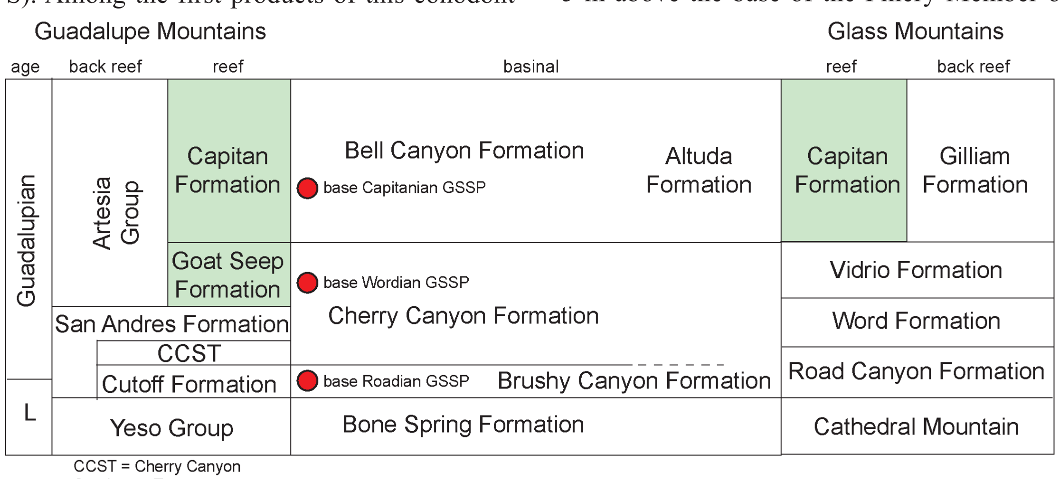

Fig. 1. Correlation of the Guadalupian lithostratigraphic units in the Guadalupe Mountains (left) and Glass Mountains (right) and locations of the three Guadalupian GSSPs (from Lucas, 2023). Note that the Brushy Canyon, Cherry Canyon and Bell Canyon formations make up the Delaware Mountain Group.

Formation, but at the Frijole section it is about 19 m above the Pinery Member base. This means that either the stratigraphic range of *J. postserrata* at the Frijole section is incomplete, the member boundaries are diachronous or that sedimentation rates vary widely between the Frijole section and the section at Nipple Hill. The former seems likely and raises questions about how well and how widely the GSSP level can be correlated, even over a very small area.

Thus, in a little over 20 years the need to redefine, and even move, at least two of the Guadalupian GSSPs is clear. How did this unworkable Guadalupian chronostratigraphy come to be?

The answer lies in politics and in the use of conodonts in chronostratigraphy. Indeed, the Guadalupian chronostratigraphy provides an excellent example of how the GSSP method can fail to produce a stable chronostratigraphy that enables precise correlations. I have already discussed these problems at length with reference to other examples (Lucas, 2018, 2020, 2021), so I will only present a short evaluation here.

To create GSSPs, the ICS has a leadership and a series of subcommissions, each devoted to a specific part of the chronostratigraphic timescale, usually to a system. A set of rules and procedures have been specified by which GSSPs are selected. Within each subcommission, working groups are created to ultimately present a GSSP candidate to the subcommission members as a whole for a vote to decide on a GSSP. As Cowie et al. (1986, p. 6). put it, "boundary stratotype definition is a normative question which can be settled by a vote." The fact that voting within a bureaucratic structure is an integral part of the process of selecting and approving GSSPs naturally introduces politics into that process.

During the late 1990s, conodont micropaleontologists had most or all of the political power in the SPS. Opposition to the Guadalupian chronostratigraphy had come largely from Soviet paleontologists (for example, see articles in *Permophiles* 29 in 1996) and was swept aside by 1999. The GSSPs for the bases of the three Guadalupian Stages were approved by SPS vote in 2000, and the ICS voted approval in 2001. The fact that almost nothing was published about the GSSPs, either in the broader technical literature or in Episodes, is likely unique in GSSP history. And, a reading of the debate in *Permophiles* 29 and elsewhere, and the fact that the GSSPs were approved without published details, suggests to me that politics were involved. And, the fact that those GSSPs are in one of the most fossiliferous marine Permian sections on Earth, a section with fusulinids, brachiopods, ammonoids and many other kinds of fossils (as first detailed long ago by Girty, 1909), but that no fossils other than conodonts played a role in GSSP definition (there were no secondary signals) is also noteworthy.

However, the other unfortunate aspect of the Guadalupian GSSPs is the use of conodonts as primary signals for their defined bases. As I have noted many times, using Permian conodonts for chronostratigraphy faces three problems: (1) a relatively young, little tested and not well agreed on conodont taxonomy; (2) the idea that the GSSP signal should be an arbitrarily chosen point in a conodont chronomorphocline, an approach open to serious theoretical and methodological questions; and (3) the fact that the stratigraphic ranges of many Permian conodonts are not well established. The current state of the Guadalupian chronostratigraphy well exemplifies all of those problems. It presents another strong argument as to why we should not be using conodonts as primary signals in Permian chronostratigraphy.

However, I see the SPS as having painted itself into a corner with regard to conodont biotic signals of GSSPs. Few fusulinid and ammonoid workers (a global problem) remain to allow those taxonomic groups to attain a lead a role in GSSP definition. One Permian GSSP remains to be defined, the Kungurian base, and only conodonts are being considered as a primary signal of that GSSP. The SPS is close to a complete Permian chronostratigraphy with conodont biotic events as primary signals. And, the Guadalupian chronostratigraphy reveals some of the problems that can arise when using conodont biotic events as primary signals.

Thus, it is clear that at least the bases of the Roadian and Wordian need to be redefined, and likely moved to other locations. Unfortunately, if the redefinition will use conodont biotic events as primary signals they may, in 20 years or so, need to be redefined again!

My thanks to Charles Henderson for his comments on an earlier version of this article and for his good cheer in our ongoing disagreement about the use of conodonts in chronostratigraphy.

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The Permian Guadalupian stages: how collaborative science and conodonts can produce a workable chronostratigraphy

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Spencer Lucas in his article with a 'similar' title in this issue of *Permophiles* states "the fact that almost nothing was published about the Guadalupian GSSPs, either in the broader literature or in Episodes, is likely unique in GSSP history" and "the fact that the GSSPs were approved without published detail suggests… that they were pushed through without documentation". I agree that these are mostly facts. But the perception of these facts may shift with time as procedures to develop GSSPs are revised. These facts need to be viewed in the context of the time in which these GSSPs were proposed. Spencer argues that Guadalupian chronostratigraphy is unworkable and yet the stages have been correlated successfully in many locations around the world and by many workers (see my talk "Progress, problems and perspectives for the base-Roadian and base-Wordian GSSPs" presented Oct 24, 2023 and saved on the SPS website). I agree that it is also a fact that these GSSPs need to be better documented, correlated and details published. This was the impetus for the collaborative research effort led by Shuzhong Shen to revisit, recollect and test the GSSP sections that outcrop in the Guadalupe Mountains.

Let's take a quick look back. We could go back to the 1908 USGS Professional Paper 58 by George Girty – the 651 pages have many images of the Guadalupian fauna, but perhaps not as well documented in detailed sections as we would like today. We could go back to the presentation at the 1991 Perm, Russia meeting by Brian Glenister as well as the publication that followed a year later (Glenister et al., 1992). The 1991 meeting of course was held on the 150th anniversary of Sir Roderick Murchison naming the Permian System. The paper presented and published by Brian was entitled "The Guadalupian: proposed international standard for a Middle Permian Series". This paper includes a discussion on the 'definition' of the base (=first appearance of *Mesogondolella serrata* ?=*M. nankingensis*; now called *Jinogondolella nankingensis*), description of stratigraphy and facies and biota including ammonoids and fusulinids (*Parafusulina boesei* – *Skinnerina* sp. Zone for Roadian). It points out historical priority (Girty, 1908), paleomagnetics and geochemistry. It suggests the Wordian could be defined by the ammonoid change from *Demarezites* to *Waagenoceras*. All of us should review this and subsequent papers as they demonstrate that the Guadalupian Series was not pushed through; instead these papers document the historical struggle to getting this standard accepted. I remember the Perm meeting well and during one of the business meetings, there was an intense debate about whether the Permian should have two series (Lower and Upper) or three (Lower, Middle, Upper) – obviously the introduction of the Guadalupian meant three series. This 1991 Perm meeting and the earlier 1987 Beijing meeting (International Congress on the Carboniferous and Permian or ICCP) really opened my eyes to what I would call the 'modern era' of Permian studies. I feel fortunate to have attended both meetings in 1987 as a PhD student and in 1991 as a young Professor. The base of the Permian was a big topic in 1987 and in 1991 the possibility of a Middle Permian was contentious. Many discussions followed and a proposal to adopt the Guadalupian and component Roadian, Wordian and Capitanian stages was published in *Permophiles* 34 (Glenister et al., 1999) prior to the XIV ICCP that I chaired at the University of Calgary in August 1999. SPS met during that meeting and a vote was called. The vote results that led to the adoption of the Guadalupian and its stages by SPS was published in *Permophiles* 35 (p. 4; Dec. 1999). I voted yes and this was my very first vote having just become a voting member; I became SPS Secretary the next year. Spencer Lucas (this issue) mentions that in the 1990's, conodont micropaleontologists had most or all of the political power in the SPS. I am not so naïve to suggest that politics don't play a role in science, but maybe in 1999 I may have been. However, I certainly didn't sense any political decisions were being made by this vote, in contrast I felt a sense of pride that I was part of this decision. Looking back I think all appropriate procedures were taken to achieve this vote. There were years of discussion mostly between 1991 and 1999. In *Permophiles* 29 (p. 2; December 1996), the results of a vote were published that showed nearly unanimous support for the three series and nine stages that currently constitute the Permian; they were soon formalized in Episodes (Jin et al., 1997). These stages were very different from those presented by Furnish (1973). There was opposition largely from Soviet paleontologists, but not against the conodont based chronostratigraphy as suggested by Spencer (this issue), but rather they mostly lamented the fact that Ufimian, Kazanian and Tatarian would not be part of the international Permian Time Scale. As always, these voices were heard in *Permophiles* – they were not swept aside, but votes and decisions provided a clear course of action. A Guadalupian proposal was prepared. It was voted by SPS, passed, presented to ICS at the 2000 International Geological Congress in Rio de Janeiro, Brazil and ratified by IUGS in 2001. So what is the problem? Is the Guadalupian unworkable?

GSSP proposals today provide a definition or point in a section that is marked by some significant event – usually the FAD of a species, but it could be a non-biologic event. The boundary is defined only at that one section and point. The correlation of that point is achieved by using all possible stratigraphic tools available given that it is unlikely for the "defining" species to be present everywhere, and if present, it is uncertain that the local first occurrence (I prefer FO rather than LO or lowest occurrence) exactly coincides with the FAD. A proposal prepared today would present all of these detailed data to define and correlate. I think it is fair to say that in 1999 many GSSP proposals emphasized the definition at the section more than the global correlation. It is in this light that the base-Roadian, base-Wordian, and base-Capitanian were proposed. The first paragraph of the proposal (Glenister et al., 1999) indicates that qualifications of the Guadalupian as a standard were already published (Glenister et al., 1992). The proposal then provided critical new conodont data, absolute dates, and paleomagnetics. It discussed the prerequisites for GSSP definition, provided data on fusulinid and ammonoid biostratigraphy, suggested that a magnetic reversal lies close to the Wordian/Capitanian boundary and documented an age of 265.3 Ma within the Wordian. It suggested that more work could be done on radiometric ages and paleomagnetics in the future, but that adequate detailed information was available worldwide to select the GSSPs. It is a fact that there is always more work that can be done. It is possible that the 1999 proposal, if presented in the same form today, might be sent back by ICS with a suggestion to do more work and separate into three proposals. However, at the time, the Silurian was fully ratified (8 stages defined in 1980 and 1984), but for the Permian only the base-Asselian (base-Permian) was ratified in 1996. It was definitely time to make more progress on the Permian. Looking back the only issue I can see is that the various authors, especially Bruce Wardlaw, did not follow-up and publish a detailed article in Episodes. This has now been done for the Capitanian (Shen et al., 2022) and still needs to be done for the Roadian and Wordian (see the call for new working groups in this issue).

Let's look at each boundary that Lucas (2024; this issue) considers to be unworkable. For the base-Roadian he indicated that the FO (his LO) of serrated gondolellids was considered to be the primary signal, but serrated conodonts have been found well below the stratotype level. This is true, but the serration differs and only a few specimens bear this serration. From a population perspective (see Mei et al., 2004) it seems that the "gene expression" for serration took time to dominate the population and during this time it changed. This early form occurs in South China (Maweishan Section) as well as in the Guadalupes and could be named a new species. The GSSP level will still be marked by the FAD of *Jinogondolella nankingensis*. There remains a question about the exact level of the point as determined with transitional morphotypes. Lance Lambert (for the 1999 proposal) in consultation with Bruce Wardlaw arbitrarily chose a structure on the lower surface keel, but upper surface serration in lateral view may be more characteristic. This needs to be better documented. It is possible that the boundary could be raised by a few metres or the current level could work since the most characteristic forms of *Jinogondolella nankingensis* are always abundant above this level. A new working group will consider these and other questions.

Spencer indicates for the base-Wordian that the primary signal is the FAD of *J. aserrata*, but it was not recovered in the GSSP bed and the FO is well below the boundary. This is true, but new research shows that the FO of *J. aserrata* is found a few metres below the GSSP as morphotype B of Yuan et al. (2021). In my view, morphotype A in the paper by Yuan et al. (2021) is not *J. aserrata*, but rather a transitional morphotype. This distinction was actually made in the original Guadalupian proposal (p. 4 of Glenister et al., 1999), which said the "transitional morphotype from *J. nankingensis* to *J. aserrata* displays a rounded posterior termination". So this GSSP can be revised to a new level, possibly with a new marker, but it could also be moved downward a few metres at the current location. It could actually stay right where it is since typical specimens of *J. aserrata* are always common above the level – for example, the holotype comes from the overlying South Wells Member. It comes down to what level of precision we expect as we correlate around the world. Remarkably, for a boundary that is potentially unworkable, it has been correlated in many different regions from South China to Oman. A new working group will consider these and other questions.

For the base-Capitanian the primary signal is the FAD of *J. postserrata*, which is well documented at Nipple Hill and a newly developed section called Frijole (Shen et al., 2022). The FO of *J. postserrata* is 5 m above the base of the Pinery Member at Nipple Hill, but 19 metres above at Frijole. Spencer Lucas (this issue) states that this means that the boundary may be diachronous even over a very small area. However, the FO occurs about 5 metres above the last sandstone at each section – the underlying sandstone varies in thickness, which is true for many facies in the region. In fact, the boundary can be precisely correlated in this "very small area" and correlated to South China. This wide correlation has been documented by Shen et al. (2022).

Spencer doesn't like the GSSP process and procedure largely, it seems, because it uses FOs and FADs of conodont species. He suggests that GSSPs would be so much better if they used non-biologic markers (Lucas, 2018, 2020). In his opinion, conodont taxonomy is relatively young and little tested. I wonder how old does a discipline have to be, before it can be considered mature? American papers on Permian conodont biostratigraphy date to at least 1971. Conodont workers are making new discoveries and revising old ideas, which suggests to me that the science is active and dynamic. In many respects conodonts are the ideal fossil for GSSP work since the ultimate goal is defining a "point" and conodonts tend to be abundant in most marine samples. Other fossils like ammonoids are very important, but productive levels tend to be sporadic, except perhaps in condensed Hallstatt facies.

I think the much more important question is "where would we be without the GSSP process"? In my view, we would still be debating whether the Permian should have 2 or 3 series and arguing about which stage names should be adopted. Instead, because we have nearly finished the Permian GSSP process, we are able to do exciting research on how to more precisely correlate and characterize the events that occurred during the Permian. These events include many sea-level changes, the penultimate ice age, major climate change, and Earth's greatest extinction event. Research on these topics seems much more pertinent in 2024.

Acknowledgments

I wrote this note as a reply to the article by Spencer Lucas and I appreciate that his challenges force me to rethink and defend past positions. He provided me his first draft and asked for comments and suggested I reply. We have a number of projects ongoing in which we use conodonts to help resolve some Lower Permian correlations – it turns out that Spencer is very good at collecting productive conodont samples. Thanks Spencer - I look forward to more good research together while we are both still able.

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Carnic Alps stratigraphy – quo vadis? (A comment to Calvo Gonzalez et al., 2023)

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Introduction

Two extended abstracts (Calvo-Gonzalez, 2022; Calvo-Gonzalez et al, 2023a) dealing partly with the Carnic Alps stratigraphy have been recently presented in *Permophiles* before being published in *Facies* journal (Calvo Gonzalez et al., 2023b). The concerns arising from the publication are related to the biostratigraphic correlation of the studied sections in the Carnic Alps and the supposed change in cyclic character during the Early Permian leading to the hypothesis of a worldwide glacial demise of the LPIA at the Asselian/Sakmarian boundary.

It is admitted that the stratigraphic relationships among the lithostratigraphic units in the Carnic Alps is still under discussion (Fig. 1), but those hypotheses and correlations once settled in the scientific community will be further cited by other authors without scrutinising the regional data.

The Carnic Alps (Austria/Italy) (Fig. 2a, b) have attracted geologists since the mid-19th century, and progress has been made since then in refining the stratigraphic subdivision. Studies such as those dealing with the Late Ordovician – Silurian section at Cellon (Walliser, 1964), the Devonian/Carboniferous section at Grüne Schneid (Kaiser et al., 2006), the outcrop and cores encompassing the P/T boundary at Gartnerkofel (Holser and Schönlaub, 1991), and many others have inspired

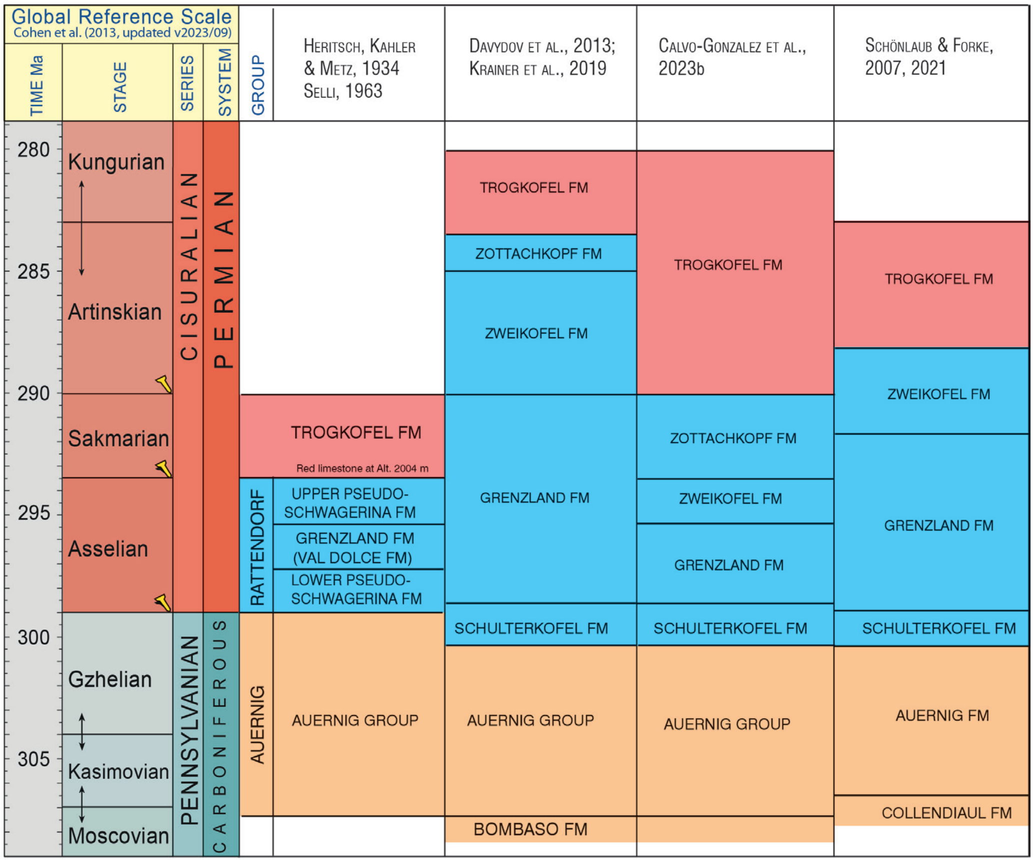

Fig. 1. Lithostratigraphic subdivision of the Pennsylvanian/Cisuralian in the Carnic Alps.

scientists around the world to understand climate perturbations, mass extinction events and the recovery in Earth's history. A compilation of the geological research conducted in the Carnic Alps over the last 150 years have been recently published (Schönlaub and Forke, 2021).

For international researchers, who want to elucidate specific geological questions, it is important to rely their concepts and interpretations on a sound lithostratigraphic subdivision of the studied area, which depends on the expertise of mapping geologists and stratigraphers, who have worked for decades in the region.

Independent studies by regional mapping geologists and stratigraphers have often led to different ideas and concepts of the stratigraphic subdivision of the Palaeozoic sequence in the Carnic Alps. The position on either side of the Italian-Austrian border may have further contributed to the conflicting stratigraphy in the literature. A working group has therefore made considerable effort to arrive at a unified and generally accepted lithologic subdivisions in the Carnic Alps for the pre-Variscan sequence (Corradini and Suttner, 2015).

Such a joint campaign is unfortunately still missing in the post-Variscan sequence and in the last 30 years, the upper Palaeozoic stratigraphy has undergone several changes, some of them are not without contradiction among researchers (Fig. 1). Overviews had already been given by Krainer and Davydov (1998) and in the explanatory notes of the geological map of the upper Palaeozoic rocks in the Nassfeld area (Schönlaub and Forke, 2007), which was updated 2019 in the guidebook published in the frame of the 19th ICCP (Cologne) (Novak et al., 2019). Schönlaub and Forke (2021) provide a detailed summary of the current knowledge of the Palaeozoic succession and critically examine the available data to separate facts from interpretation serving as a basis for further discussion. As the recent book of Schönlaub and Forke (2021) is written in German language, some of the major points are repeated here in English with a focus on the Lower Permian rocks in the Carnic Alps. Some references are also given to the stratigraphy of the adjacent Karavanke Mts (Austria/Slovenia) (Fig. 2a, c).

The relevance of the Palaeozoic rocks in the Carnic Alps lies in the diverse and exceptional preservation of fossil biota and the long tradition of research in various fields of taxonomy, biostratigraphy, microfacies, and sedimentology. Sections are generally easy to access, and some sequences form spectacular steep cliffs with ideal outcrop conditions for detailed bed-by-bed studies.

Grenzland Formation (Asselian-lower Sakmarian)

Lithostratigraphy

The Grenzland Formation is best exposed in the area from Schulterkofel to Rudnigalm at the Austrian/Italian border, forming gently hilly mountain pastures (Rattendorfer Alm, Rudnigalm) around Trogkofel (Fig. 2b). A narrow strip also runs along the northern foothills of Gartnerkofel.

Compared to the siliciclastics of the Auernig Formation, coarse conglomerates are rare in the Grenzland Formation, with

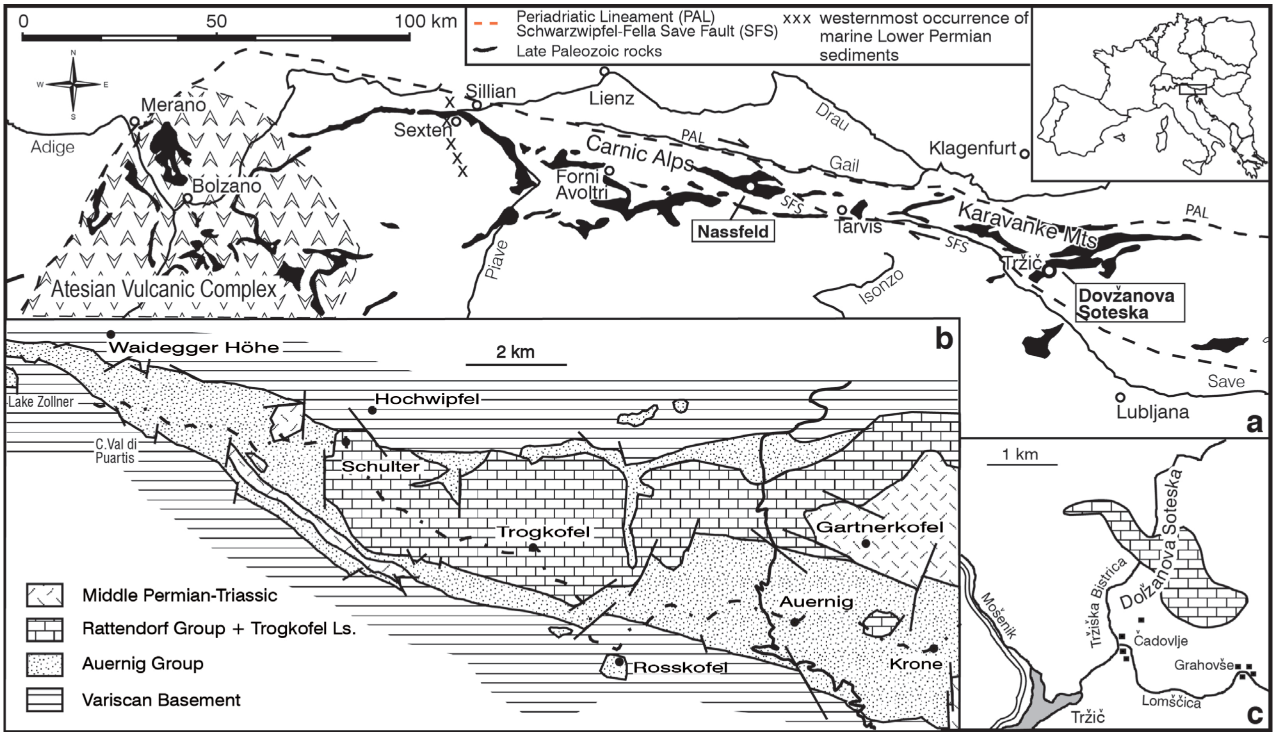

Fig. 2. a) Location map of upper Palaeozoic outcrops in the Southern Alps; b) Simplified geological map of the Nassfeld Basin (central Carnic Alps, Austria/Italy); c) Outcrop of Lower Permian rocks in the Dovžanova Soteska (Karavanke Mountains, Slovenia).

sandstones and shale dominating. Furthermore, as noted by Heritsch, Kahler and Metz (1934), the occurrence of oncolitic limestones (referred to as "Großoolithe") is a significant distinguishing criterion for the mapping geologist. This helps differentiate the Grenzland Formation from the similar clastic units of the Auernig Formation. Oncolitic limestones seem to have stratigraphic importance, being a characteristic feature in many Tethyan sequences of the Asselian-Sakmarian. For example, they are widespread in the Chuanshan Formation in China. Shi and Chen (2006) suggested a very shallow (up to 10 m), strongly hydrodynamically influenced shelf in a tropical warm marine environment based on the distribution of facies belts on the Yangtze Platform. The abundance of fusulinids and green algae in oncolitic limestones also suggests deposition in well-lit areas. Frequent waves and/or tidal currents in shallow water are believed to contribute to the formation of uniform, round oncoids.

On the Italian side, diverse trace fossil assemblages in the lower part of the Grenzland Formation have been studied more closely, suggesting deposition in the proximal delta to distal prodelta setting with water depths ranging from several tens of meters to well over 50 meters (Baucon et al., 2015). This is significantly deeper than the assumed depositional environment of oncolitic limestones. Calcareous intercalations are rare in this studied sections, and marine fossils (brachiopods, echinoderm remains) usually occur only in the distal prodelta settings. On the other hand, in the uppermost part of the Grenzland Formation on the western side of the Zweikofel massif, approximately 2 meters thick red, yellow and green paleosoils with root traces have been preserved in the clastic sediments, indicating subaerial exposure (Schönlaub and Forke, 2007).

Although the Grenzland Formation in some parts is characterised by cyclic alternation of mixed clastic-carbonate sedimentation, the sections have been insufficiently studied in terms of their cyclostratigraphy and sea-level amplitudes.

Due to the incompetent nature of the clastic sediments, the sequence is prone to disintegration, small landslides and sagging of mountain slopes (Lotter and Moser, 2007). The Grenzland Formation is therefore represented by relatively short sequences, and cumulative thickness can only be approximated. For this reason, only boundary sections to the underlying and overlying units were defined (Novak et al., 2019) and supplemented by additional incomplete reference sections (see also in Krainer, 2012). The base of the Grenzland Formation can be best studied in the area around Schulterkofel, where the transition to the underlying Schulterkofel Formation is exposed in several short sections. The lower and middle parts are mainly exposed along the Rattendorfer Schneid (Italian-Austrian border region=Grenzland). The upper parts of the Grenzland Formation are best exposed on the western slope of the Zweikofel massif (with defined base of overlying Zweikofel Formation.) (section ZK in Fig. 3) and in the Trogkar east of Trogkofel (sections SL/GR in Fig. 3) (with the transition to the overlying Zottachkopf Formation).

In the central part of the Southern Karavanke Mountains (Slovenia), contemporaneous sediments of the Lower Permian sequence also show a diverse facies development. The section along the Dovžanova Soteska near Tržič (Fig. 2c) is composed of massive to thick-bedded carbonate rocks with subordinate siliciclastics (Dovžanova Soteska Formation), where outer platform and slope sedimentation prevail followed by a bedded limestone sequence of the inner platform (Born Formation)

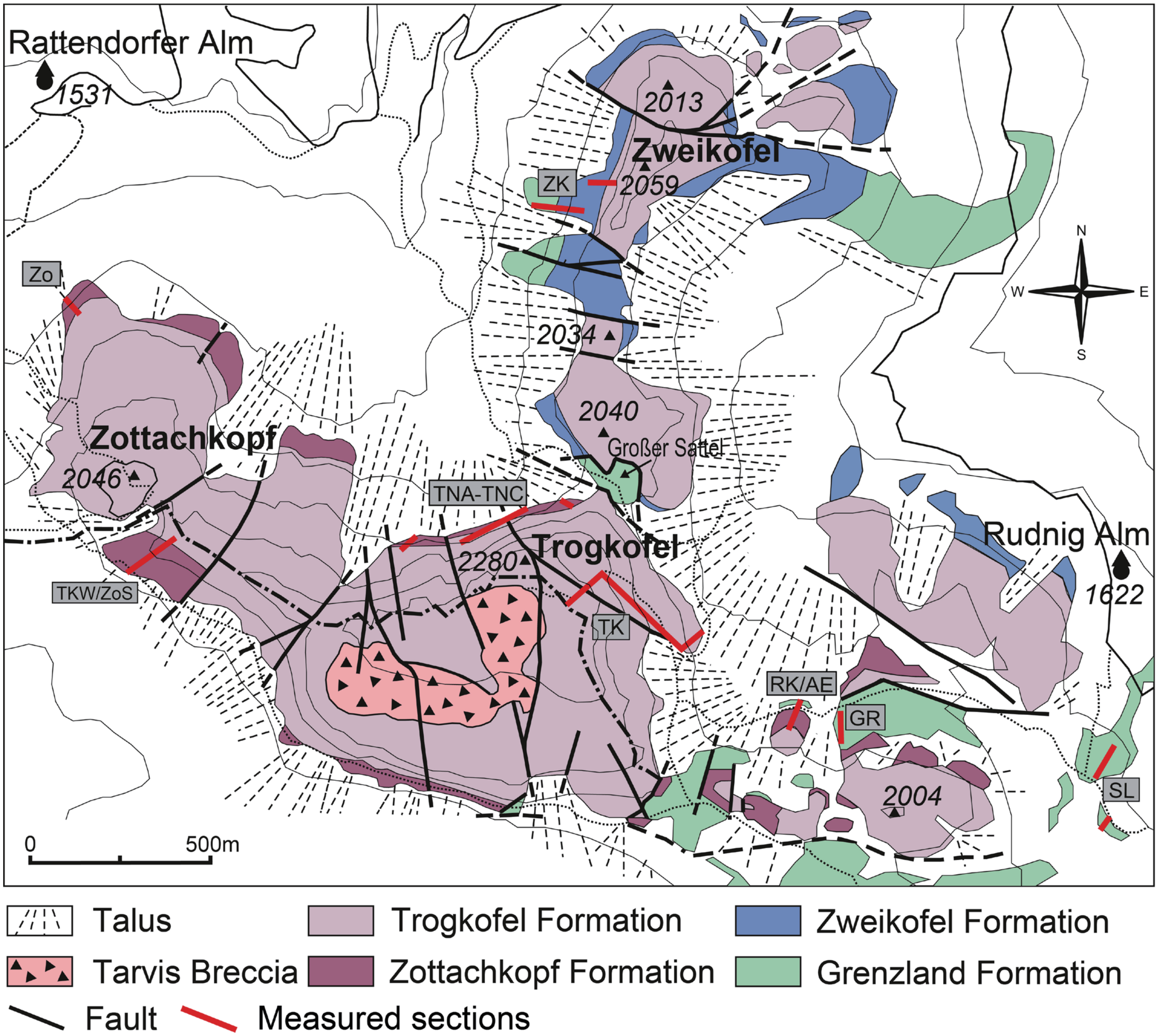

Fig. 3. Detailed geological map (after Schönlaub and Forke, 2007) of the area between Zottachkopf, Trogkofel and Zweikofel with outcrops and measured sections of different formations. Grenzland Formation (SL, GR), Zweikofel Formation (TNA-C, TKW/ZoS, Zo, RK/AE) and Trogkofel Formation (TK).

(Novak, 2007) (Fig. 4). This variability of depositional settings between Carnic Alps and Karavanke Mountains is in striking contrast to the mixed clastic-carbonate sequences in the Upper Carboniferous sequences of the Auernig and Schulterkofel formations with a more uniform facies development. Beside changes in the amplitude of sea-level fluctuations, facies differentiation may be related to extensional tectonics affecting the southern Alpine region in the Early Permian (Wopfner, 1984). Evidence for this is the significant volcanism in the western Dolomites. The main phase 285-275 million years ago (late Artinskian-Kungurian) has been dated through radiometric ages, but the oldest eruptions are already documented 290 million years ago (base Artinskian) (Visonà et al., 2007).

Biostratigraphy

The biostratigraphy of the Grenzland Formation in the Carnic Alps is primarily based on fusulinids and rare plant fossils (Fritz and Krainer, 2007). Since limestone intercalations mainly occur in the middle and upper parts of the Grenzland Formation, dating the lower part is challenging. A first limestone bed in the basal Grenzland Formation on the eastern slope of Schulterkofel yields a faunal association with *Sphaeroschwagerina carniolica*, *Pseudoschwagerina extensa*, and *P. turbida*. Together with *Pseudoschwagerina confinii* and *P. aequalis*, described from the lower part of the main section along the Rattendorfer Schneid, they indicate a middle to late Asselian age. Faunal associations with *Paraschwagerina dlakhshanensis-P. paranitida* and early representatives of the genus *Zellia* from the upper part of the Grenzland Formation around Zweikofel and Trogkofel are assigned to the Sakmarian (Forke, 2002). Last *Sphaeroschwagerina* (*Sph. glomerosa*, *Sph. asiatica*) are recorded on top of the Grenzland Formation. Higher diversity of fusulinid faunas from the middle Asselian to the early Sakmarian (Forke, 2002), accompanied by conodonts (Buser and Forke, 1996), are described from the Slovenian sections in the Dovžanova Soteska.

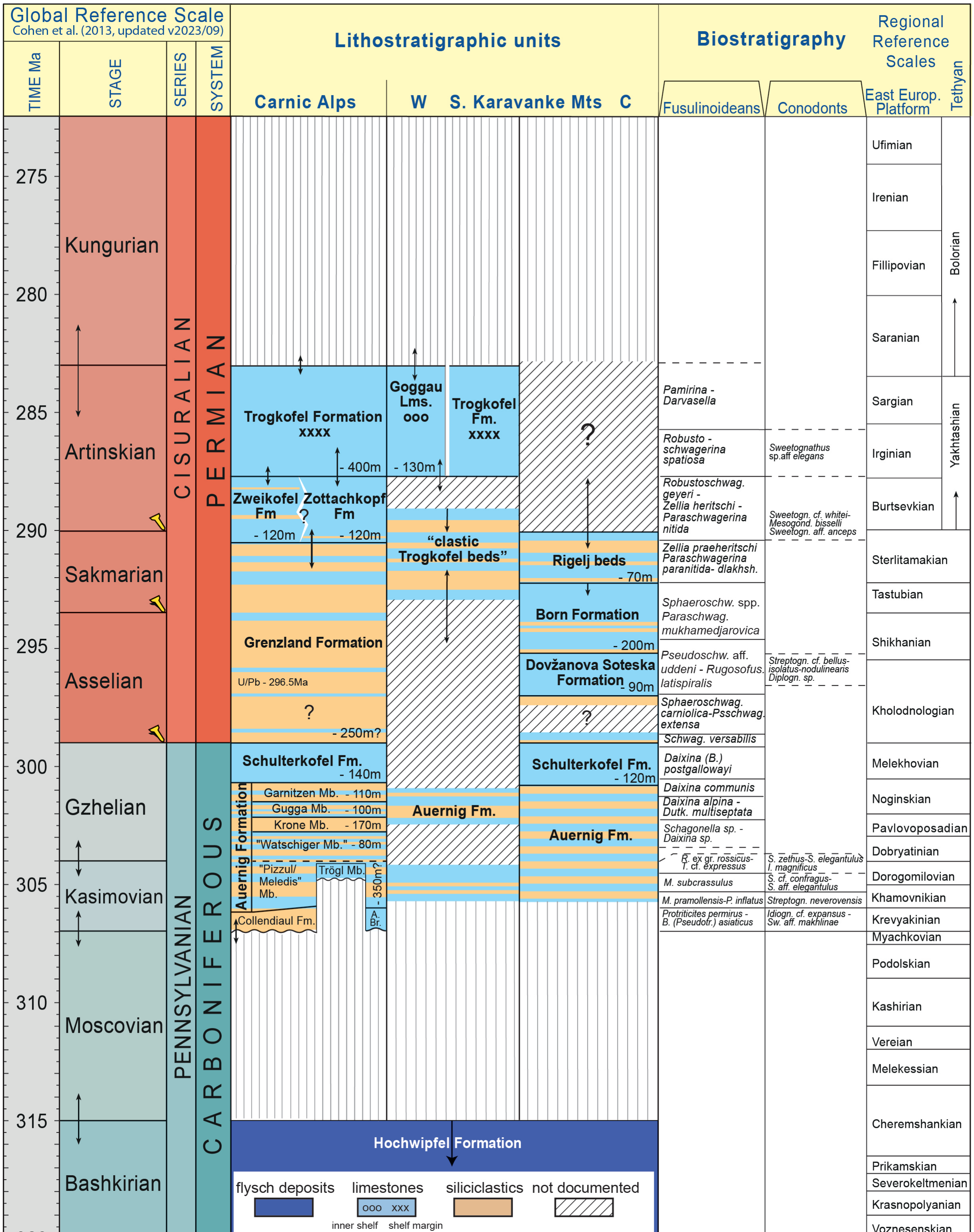

Fig. 4. Litho- and biostratigraphy of Carnic Alps and Karavanke Mountains (after Schönlaub and Forke, 2021).

Radiometric age

Krainer (2012) described a volcanic ash layer from near the top of the lower part of the Grenzland Formation, and its age has been dated to 296.5 million years ago (base of Shikhanian= middle/late Asselian boundary in the Urals), consistent with the available biostratigraphic data. This implies that lower to middle Asselian rocks are poorly represented, or even partly missing in the Carnic Alps. Similarly, the interval from the uppermost Carboniferous Schulterkofel Formation to the middle-upper Asselian Dovžanova Soteska Formation, represented by siliciclastic rocks in the Karavanke Mountains, is lacking biostratigraphic data. Geological interpretation in the

Karavanke Mountains is further hindered by the strong tectonic fragmentation of stratigraphic successions.

Zweikofel/Zottachkopf Formation (upper Sakmarian – Artinskian)

Lithostratigraphy

The Zweikofel Formation was originally designated as "Oberer Pseudoschwagerinenkalk" (Heritsch, Kahler and Metz, 1934). The predominant grey-bedded limestones at the western slope of Zottachkopf were chosen as the type section (section Zo in Fig. 3), even though the transition to the underlying Grenzland Formation is not exposed in this section. In a re-evaluation, the formation name was emended to the Zweikofel Formation. (Krainer, 1995) and complete sections of the Zweikofel Formation were studied at the western cliff of Zweikofel (section ZK, lectostratotype) and in the Garnitzen gorge (Krainer and Schaffhauser, 2012). Due to the continued alternation of mixed carbonate – siliciclastic deposition in the Zweikofel Formation, the base has been variously defined in the past (Schönlaub and Forke, 2007; Krainer and Schaffhauser, 2012). However, the precise definition by Felser and Kahler (1963) takes precedence for historical reasons (see discussion in Novak et al., 2019).

Sections through the Zweikofel Formation at Zweikofel (ZK) and in the Garnitzen gorge are characterised by a repeated alternation of oolitic, bioclastic, and oncolitic limestones, interrupted by thin siliciclastic beds (quartz conglomerates, sandstones). In the type section at Zweikofel thickness attains around 120 m with six thin siliciclastic intercalations. Transition to the overlying Trogkofel Formation is para- and partly disconformable with a local intercalation of carbonate breccias (see details under Trogkofel Formation).

Separated by a prominent transpressional fault trending across the “Grand Saddle” (Großer Sattel) in the NW-SE direction, bedded oncolitic and bioclastic limestones are also exposed around the base of Trogkofel massif (including the Zottachkopf). Along the northwestern and southern slopes of Trogkofel massif, the upper part forms a continuously exposed succession with a sharp but conformable change to the massive limestones of the Trogkofel Formation. However, the base of the section is covered by scree at the base of Trogkofel and Zottachkopf. Only in the Trogkar on the eastern side of the Trogkofel massif (section RK/AE in Fig.3) the lower part is exposed with the transition into the underlying Grenzland Formation (Forke, 1995; Schönlaub and Forke, 2007; Novak et al., 2019; Schönlaub and Forke, 2021). This area is strongly affected by Quaternary mountain splitting, disintegration and sagging of slopes (Lotter and Moser, 2007), but the lithological succession has been reconstructed through detailed mapping of the area (Forke, 1994). The appearance of characteristic lithological units in several locations allows the compilation of a composite section. The top of the mixed clastic-carbonate sequence assigned to the Grenzland Formation is marked by an approximately 2-3 m thick quartz conglomerate bed with several fining-upward sequences, followed by poorly exposed sandstones and shales, with a thin, sandy limestone bed containing frequent fusulinids. Along the ascent to the Troghöhe on path 413, massive bioclastic grainstone is followed in the upper parts by limestones displaying boundstone texture with highly diverse fossil assemblages (Samankassou, 2003), which have been assigned to the base of the Zweikofel Formation. At the top, these limestones are partially reddish showing karstification features with fine clay seams and sandstone lenses indicating subaerial exposure. This is followed by approximately 3-4 m of oolitic grainstone, sometimes with intercalated lithoclastic layers and sandy infillings. Subsequently, thinly bedded, partially intensely red-coloured limestones follow. The thin bedding is attributed to strong compaction and pressure solution with an increased proportion of clay minerals. The intense red colour is associated with low amounts of hematite (Fe_2O_3), possibly formed in connection with secondary dolomitization (Forke, 1995) during early diagenesis. The conspicuous red limestone unit with large inflated schwagerinids (*Robustoschwagerina geyeri*) has attracted attention early on by F. Kahler and G. Kahler (1938), but at that time were considered to belong to the “Trogkofel limestone” due to their intense red colour. In the upper part, the limestones become thicker bedded, transitioning into dark oncolitic limestones with common *Zellia*, as also seen in other sections at the base of the northern cliff of Trogkofel and Zottachkopf.

During subsequent investigations at the northern foothill of Trogkofel, the term Zottachkopf Formation for the bedded limestones below Trogkofel and Zottachkopf as well as in the Trogkar area was established due to the facies differences (Schaffhauser et al., 2010). The Zottachkopf Formation especially differs from the typical Zweikofel Formation by the rare presence of oolitic limestones and siliciclastic intercalations. The field evidence from previous mapping campaigns of the stratigraphic relationship of the Zottachkopf Formation to underlying Grenzland Formation in the Trogkar (see above) was not accepted, but instead it was postulated that the Zottachkopf Formation stratigraphically lies between the Zweikofel Formation and the Trogkofel Formation. However, no physical stratigraphic succession exists, where the superposition of the Zweikofel Formation above the Zottachkopf Formation can be proven. It is well known that lithostratigraphic units do not necessarily represent chronostratigraphic units. The fault contact across the “Grand Saddle” with an unknown vertical and lateral displacement of Zweikofel and Trogkofel massifs complicates the establishment of precise chronostratigraphic surfaces. Biostratigraphic correlation of the fauna in the two formations may be used to approximate the timing of deposition. This will be discussed in the following part.

Biostratigraphy

Fusulinids (and in the lower part conodonts) are the most important fossil groups for the biostratigraphic subdivision and correlation. In addition, small foraminifera and algae are frequently represented in the Zweikofel and Zottachkopf formations and have been the subject of taxonomic and paleoecological studies (Flügel, 1971, 1977; Vachard and Krainer, 2001, Krainer et al. 2019). Occasional occurrences of various invertebrate groups (corals, brachiopods, trilobites, bryozoans) complete the picture (Heritsch, 1934; Ernst, 2000; Schraut, 2019).

Historically, the former "Upper Pseudoschwagerina Limestone" in the Zottachkopf section (Zo in Fig. 3) was characterised by the abundantly occurring fusulinids of the genus *Zellia* Kahler and Kahler (1937) and *Robustoschwagerina geyeri* F. Kahler and G. Kahler, (1938) was described from the red limestones (section RK/AE in Fig.3) in the Trogkar east of Trogkofel.

In the 1990s, the limestones of the Zweikofel/Zottachkopf Formation were studied in more detail (Forke, 1995, 2002). Sections from the Trogkar area, Zottachkopf (northwestern foothill and southern slope), as well as the western cliff of Zweikofel and Garnitzen gorge were sampled for both fusulinids and conodonts. An accompanying microfacies study aimed to consider the composition and faunal diversity with changing depositional settings.

As a result, all sections from Zweikofel and Zottachkopf formations had displayed a similar species composition but with differences in the range and distribution of species and genera complicating a precise local correlation of the sections. In the lower half of the Zweikofel section *Robustoschwagerina* is more common, while in the Garnitzen gorge, it is very rare and instead pseudofusulinid species dominate (Forke, 2002). In the red limestone of the Trogkar section, *Robustoschwagerina geyeri* occurs together with common *Paraschwagerina inflata*, *Boultonia willsi*, *Quasifusulina nimia*, *Dutkevitchia complicata*, *Rugosochusenella* spp., and other pseudofusulinids (Forke, 1995). *Paraschwagerina nitida* is serving as a guide form for the lower part of the Zweikofel/Zottachkopf Formation, as it is present in the lower part of the Garnitzen gorge and Zweikofel sections (ZK), the red limestones in the Trogkar east of Trogkofel, and at the base of the Zottachkopf section (Zo). *Paraschwagerina nitida* has shown a distinct phylogenetic lineage from *Paraschwagerina dlakshanensis* and *P. paranitida* across the upper part of the Grenzland Formation (sections SL and GR) into the lower Part of Zottachkopf Formation in the Trogkar section, further corroborating the stratigraphic importance of the species.

Some genera and species are present in all sections but show a clear facies dependence. The group around *Zellia heritschi* is especially common in oncolitic facies in the upper part of the Zweikofel/Zottachkopf Formation. Early representatives are, however, present already in the upper part of the Grenzland Formation at Zweikofel and in the Trogkar. The genera *Pseudofusulinoides* and *Darvasites* are mainly concentrated in oolitic-bioclastic grainstone and siliciclastic influenced environments, while large pseudofusulinids are more widespread in the algae-wackestone facies. In the Trogkofel area at the direct transition from the Zottachkopf Formation to the Trogkofel Formation, isolated large *Robustoschwagerina* (*R. kahleri, R. tumida*) and *Dutkevitchia* (Forke, 1995, 2002) occasionally appear (section TKW/ZoS). Additionally, smaller pseudofusulinids ("*Perigondwania*" sensu Davydov) and *Zellia* are common.

Davydov et al. (2013) have considerably expanded the list of species from the Zweikofel section and in the upper part of the Zweikofel/Zottachkopf Formation several small schubertellid and staffellid species are of stratigraphic interest. Noteworthy is the occurrence of the staffellid genus *Pseudoreichelina slovenica* in the upper part of the Zweikofel Formation (Davydov et al., 2013; Krainer et al., 2019), previously only known from the younger Goggau Limestone. Some small schubertellid species (assigned to *Grovesella*, *Toriyamaia*) support close phylogenetic relationships to younger species of *Pamirina* (*Levenella*) described from the Goggau limestone (Kahler, 1980; Novak and Forke, 2015). Davydov et al. (2013) also reported additional fusulinids from the red limestones. Some of the described species (e.g. *Darvasella* spp., *Laxifusulina* sp.) and their stratigraphic significance are currently under discussion.

Calvo Gonzalez et al. (2023b) did not study fusulinids in particular but mentioned *Boultonia willsi* to be of stratigraphic significance. However, *Boultonia willsi* has a broad range starting in the upper part of Grenzland Formation and is a common species in both the Zweikofel and Zottachkopf formations.

From the fusulinid studies a late Sakmarian age was inferred based on the coeval faunas from Central Asia in Forke (2002). Davydov et al. (2013) and Krainer at al. (2019) had slightly shifted the Zweikofel/Zottachkopf Formation into an upper Hermagorian/lower Yakhtashian age correlated with the Artinskian.

To further constrain the age and correlation of the studied sections, conodonts are important "index fossils" due to their significance for correlation with the GSSP type sections of the Southern Urals and hence the International Stratigraphic Scale. However, they occur only infrequently in the base of the Zweikofel Formation (section ZK) and the red limestones of the Zottachkopf Formation in the Trogkar east of Trogkofel (section RK/AE).

When the conodonts from the red limestone (section RK/AE) at the base of the Zottachkopf Formation were first discovered in the early 1990s, only a limited number of species within the genus *Sweetognathus* were known worldwide. A first phylogenetic concept had been based on the development of pustulose ornamentation on the carina (Ritter, 1986). Species with a Type III carina with broad transverse ridges were generally regarded as having a FAD not before the Artinskian. Due to the weak development of the median row of pustules connecting the transverse ridges in typical *Sw. whitei*, the species from the Carnic Alps was determined with reservation (aff.). However, the co-occurrence with Sakmarian fusulinids still were posing a problem on the correlation. A careful search on available literature in Forke (1995), had already got a glimpse that some Type III *Sweetognathus* are present in upper Sakmarian sections from the Southern Urals (e.g. Isakova, 1989). Other species in the Carnic Alps material were assigned to Sakmarian *Sw. inornatus*, *Diplognathodus stevensi*, *Mesogondolella* cf. *bisselli* and the long-ranging *Hindeodus minutus*.

Additional material was processed in the following years from the lower part of the type section (ZK) of Zweikofel Formation showing a specimen with the same Type III carina. The material from the Carnic Alps was compared in Forke (2001, 2002) with collected conodont material from the Southern Urals type section at Usolka and Kondurovka in close communication with Valeryi Chernykh. At that time, the *Sweetognathus* material in the Urals collections was still very poor with only few scattered specimens and informal taxonomy. As the material in the Carnic Alps was likewise insufficient, a more detailed investigation seemed not prosperous.

The specimen encountered within the allodapic rudstones of the lower part of the Trogkofel Formation (section ZK) was likewise problematic as it has shown a Type IV carina with a tendency of a shallow trough in the anterior part of the transverse ridges. The small size indicated a juvenile specimen and in the absence of additional material, it was compared to the genus *Neostreptognathodus*. However, Valeryi Chernykh had described some species with a Type IV carina (e.g. *N. obliquidentatus*, *N. transitus*) in upper Sakmarian/Artinskian deposits. Overall, a late Sakmarian to early Artinskian age was therefore proposed for the Zweikofel Formation in Forke (2002) based on the combined approach of conodont and fusulinid species.

In the last 20 years progress had been made on the type sections in the Urals, new species and phylogenetic lineages have been proposed within the genus *Sweetognathus* and GSSPs were finally proposed and ratified in 2018 (base Sakmarian) and 2022 (base Artinskian).

In the light of the new data from the Urals type sections, the material from the Carnic Alps has then been reinterpreted again. Valeryi Chernykh proposed in Davydov et al. (2013) to assign the specimen at the base of the Zweikofel Formation as transitional from *Sw. anceps* to “*Sw. whitei*” (quotation marks are because some species names are still disputed among conodont researchers due to postulated presence of homeomorphic forms within independent phylogenetic lineages (see Henderson, 2018; Henderson and Chernykh, 2021). The more diverse conodont assemblage from the red limestone at the base of the Zottachkopf Formation are assigned to *Sw. anceps* and “*Sw. whitei*”. The specimen from the allodapic rudstones at the lower part in the Trogkofel Formation was regarded as *Sw. elegans*. A slightly younger age (early to late Artinskian) was then proposed by the authors for the Zweikofel and Zottachkopf formations.

Calvo Gonzalez et al. (2023b) recently taxonomically re-evaluated the Carnic Alps specimens a second time and assigned the specimen from the base of the Zweikofel Formation as transitional between *Sw. binodosus* and *Sw. anceps*. The specimens from the red limestones are referred to *Sw. binodosus*, *Sw. anceps* and “*Sw. whitei*”. According to the biostratigraphic correlation with the sections from the Southern Urals and South China, this would place the conodont from Zweikofel Formation into the Sakmarian s.l. and the fauna from Zottachkopf Formation more precisely into the late Sakmarian/early Artinskian.

It is therefore surprising, that they instead decided to place the Zweikofel Formation into the Asselian and the Zottachkopf Formation into the Sakmarian. This correlation is at odds with the radiometric age determination of the Grenzland Formation, the fusulinids from the Zweikofel/Zottachkopf Formation and even the conodont biostratigraphy. However, there is a striking coincidence of the correlation with the interpretation of Asselian-Sakmarian demise of LPIA. In simple words, it is assumed that due to deglaciation, the sedimentary successions around the world change from 4th order (400ky) cyclothem deposition in the Late Carboniferous/Asselian to broader 3rd order (1-3 my) (“non-cyclothemic”) depositional sequences from Sakmarian onward (Henderson, 2018). That this assumption is an oversimplification of the complex interactions of sea-level and base-level changes, available accommodation space, shelf geometries, climate and tectonic activity can be easily demonstrated by the high-frequency cyclicity in sediments from the Upper Permian Bellerophon Formation and equivalent Khuff Formation in the Middle East, where the sediments are arranged in vertical stacked patterns of 3rd, 4th and 5th order sequences, cycle sets, and cycles (Koehrer et al. 2012; Forke et al., 2014).

However, in the context of the Carnic Alps stratigraphy, the prime question is whether the cyclic/non-cyclic character of mixed carbonate-siliciclastic deposition in the Zweikofel and Zottachkopf Formation can be used to infer a chronostratigraphic differentiation. This hypothesis will be discussed in the following section.

Cyclostratigraphy

Zweikofel Formation: At the sections Zweikofel and Garnitzen gorge, the mixed siliciclastic-carbonate sediments form high-frequency cycles, some with a distinct erosive base at the bottom of the siliciclastics interpreted as sequence boundaries by Krainer et al. (2009, 2012). Many of the cycles exhibit a shallowing trend from oncolitic wackestone to bioclastic packstone and oolitic grainstone, separated by flooding surfaces. The depositional environment suggests a shallow, high-energy inner shelf area with occasional input of siliciclastic sediments from the hinterland during lowstand and early transgressive intervals. The section at Garnitzen gorge indicate a slightly more distal shelf area due to the presence of wackestone-floatstone with phylloid algae and a reduced input of siliciclastics. Carbon isotope studies (Buggisch et al., 2015) generally support the cyclostratigraphic interpretation, as $\delta^{13}C$ values near the siliciclastics are significantly reduced due to early diagenetic alteration under the influence of meteoric waters. Orbital forcing (cyclothems) with an amplitude of sea-level changes in the range of few tens of meters have been interpreted by Krainer and Schaffhauser (2012) and Gonzalez et al. (2023). Considering the high-frequency cycles in Krainer and Schaffhauser (2012) as 100 ky signal, the 20-22 cycles would represent around 2-2.2 Ma. The high-frequency cycles were grouped into six cycle sets (“depositional sequences”) which might represent 400 ky and sum up to similar 2-2.5 Ma for the Zweikofel Formation.

Zottachkopf Formation: The lower part of the formation exposed in the section in the Trogkar east of Trogkofel is showing incomplete cycles of shoals with bioclastic/oolitic limestone and small bioherms with phylloid boundstone capped by clastic intercalations with features of subaerial exposure and karstification. The upper part of the Zottachkopf Formation is composed of an alternation of oncolitic and bioclastic limestones with no clear cyclic pattern.

The section on the western foothill of Zottachkopf (representing the upper part of the Zottachkopf Formation) has been extensively studied. Flügel et al. (1971) attempted to find cyclic patterns in the depositional environment based on sedimentological parameters (bed thickness, residue contents, facies types) and the distribution of small foraminifera (Flügel, 1971). Interestingly, the measurements of the insoluble residue show a certain cyclicity, which, however, does not correlate with changes in microfacies. Therefore, Flügel et al. (1971) assume that orbital forcing generating cyclicity in successions are masked by local hydrographic factors. Differential subsidence and bypassing of siliciclastics on an extensive shallow shelf obviously played a more important role than shifts in facies settings caused by glacio-eustatic sea level fluctuations. Isotope studies (Buggisch et al., 2015) reported only one short section from the upper part of the Zottachkopf Formation showing relatively high values, but also negative shifts in carbonate beds indicating the influence of meteoric waters.

Contrary to the Upper Carboniferous cyclothems (400 ky) of the Auernig and Schulterkofel formations (with amplitudes ranges estimated 50 m to >100 m), the Zweikofel Formation exhibits high-frequency cycles (100 ky) with lower amplitudes (in the range of few tens of meters), which is in line with estimated sea-level fluctuations in other areas worldwide (Rygel et al., 2008).

Cyclic sedimentation during high amplitude sea-level changes is explained in mixed siliciclastic-carbonate environments by the reciprocal model (Van Siclen, 1958; Wilson, 1967) where main control on carbonate or siliciclastic sedimentation is represented by the base level concept (Homewood et al., 2000). During sea-level lowstand erosion on the hinterland is intense, and therefore siliciclastics are transported into the basin dominating the sedimentary succession and suppress carbonates to form. During high sea-level this siliciclastic input is reduced due to reduced erosion in the hinterland and carbonate production can set in on the now flooded shelf, resulting in a carbonate dominated facies distribution.

Carbonate-siliciclastic mixing in settings of low amplitude sea-level changes is a function of siliciclastic dilution of the carbonate sedimentation, and cyclicity follows a slightly different model (Zeller et al., 2015). In this mixed sedimentary system, an understanding of the dominant processes controlling the architecture and heterogeneity of depositional facies is required, which goes beyond the singular control of relative sea-level but also includes other processes like climate, topography of shelf, type of the carbonate factory and sediment transport.

During sea-level lowstand erosion is leading to accumulations of siliciclastic material. Flooding across the sand and siltstones during the early transgressive stage makes large amounts of siliciclastic material available for redistribution or bypassing along the shelf. This process is driven by along-shelf current systems, which require a flooded shelf with several metres of water depth to develop an effective sediment transport. During regressive intervals of relative sea-level highstand, siliciclastic redistribution is reduced, due to the lack of accommodation space for currents to develop. Carbonate deposition again dominates on the shelf and sand-sized and silt-sized siliciclastics commonly occurred as minor constituents reworked within the carbonate beds.

A definitive assessment of these controlling factors on the sediments in the Carnic Alps is hindered by the lack of spatial relationships between different sections. Due to the Alpine orogeny, the sequences at Zweikofel (Zweikofel Formation) and around Trogkofel (Zottachkopf Formation) were thrusted along the intervening fault zone and bring the areas closer together than they originally were at the time of their formation. The extent of the lateral displacement is not known but is assumed to be probably several kilometres (Schönlaub and Forke, 2021).

Trogkofel Formation (Artinskian – Kungurian?)

Lithostratigraphy

Initial investigations were conducted by Geyer (1895, 1898), who demonstrated the Permian age through the presence of fusulinids at Trogkofel. During this time, most of the lower Permian, white to reddish-coloured limestones were attributed to Trogkofel Limestone, with some stratigraphic significance even assigned to the degree of redness (Heritsch, 1933). However, it is now known that only a few of these occurrences lithologically and stratigraphically correspond to the Trogkofel Formation (Schönlaub and Forke, 2007).

Trogkofel Limestone s. str. has only been definitively identified in the Trogkofel and Gartnerkofel area. In the western part of the Southern Karavanke Mountains. (Fig. 4), limited occurrences are known, where comparable facies with Tubiphytes-Archaeolithoporella-cement reef association occurs (Novak and Forke, 2015). However, the majority of the described occurrences of "Trogkofel Limestone" in the western part of the Southern Karavanke Mountains correspond to the Goggau Limestone, whose type locality is in the tri-border area of Austria-Italy-Slovenia, close to the border town of Goggau (Coccau) on the Italian side. Stratigraphic relationships between the Trogkofel Limestone and the Goggau Limestone in the field are difficult to assess due to the strong tectonic fragmentation of the sequences. Studies on the Neogene palinspastic restoration of the Carnic Alps have inferred that the Trogkofel-Gartnerkofel area was situated just south of the Goggau - western Karavanke area and has been displaced westwards by about 30 – 40 km along the prominent Schwarzwipfel-Fella-Save fault (Forke et al., 2008, Schönlaub and Forke, 2021) since the Miocene (Fig. 1a). Sections in the central part of Southern Karavanke Mountains (Dovžanova Soteska near Tržič), long ascribed to the "Trogkofel Limestone" in many older publications, have been revised (Forke, 2002; Novak, 2007) (see above under Grenzland Formation).

The total thickness of the Trogkofel Formation at the type locality is usually given as about 350-400 meters, but there are large variations, some of which are primarily caused by subsequent erosion. Due to the partially vertical, inaccessible cliffs, the Überlacher route partially guided with fixed rope on the east side was chosen as the type section (section TK in fig. 3). The base of the Trogkofel Formation was traditionally defined at the original type section at Zottachkopf (Zo). Alternatively, it was placed at the northern cliff of Trogkofel by Schaffhauser et al. (2015) (section TNC in Fig. 3). The Trogkofel Formation consists mainly of massive, unstratified limestones; in the upper part of the type section at Trogkofel, it grades into indistinctly bedded, partly dolomitized bioclastic limestones. In the massive facies, Archaeolithoporella-Bryozoan-Tubiphytes associations with (possibly microbially induced) radial-fibrous cements predominate. Typical reef builders such as sponges, corals, or phylloid algae are only subordinate. Green algae and fusulinids are very rarely washed in the sediment. The Trogkofel Limestone has been already interpreted by Flügel (1981) as a shelf-edge reef. Both, the scarcity of fusulinids and green algae in the massive reef facies, and the high proportion of radial-fibrous cements are clear indications of a position on the shelf margin and upper slope area (Schaffhauser et al, 2015). Water depths can be compared to other Carboniferous/Permian "reef-mounds" where depths are reported to lie between 100 m and 300 m (Bahamonde, 2004). A noticeable shallowing, with the development of a grain shoal facies at the shelf edge, is evident in the upper part of the Trogkofel Formation, where fusulinids and green algae become more frequent in the bedded limestones (Schaffhauser et al., 2015).

North of the prominent fault along the "Grand Saddle" at Zweikofel, the Trogkofel Formation is developed as a lithologic succession of brecciated limestones, lithic breccias and allodapic rudstone of mixed carbonate-lithic/bioclastic composition with shale intercalations in the lower part (Schönlaub and Forke, 2007). These sections at the Zweikofel Massif were studied in detail by Krainer et al. (2009). The sequence stratigraphic interpretation suggests a gradual transgression in the transition from the Zweikofel to the Trogkofel Formation. Initially, due to the reduction of terrigenous material, a microbially induced mound facies develops, surrounded by bioclastic, sometimes rudite limestones. Subsequently, there is a sudden deepening of the sedimentary environment with local basin development and a retreat of the Trogkofel reef facies. Followed by, a renewed progradation of the reef facies over the basin facies taking place in a northerly direction, indicated by clinoforms in the summit area of Zweikofel. Since the clastic basinal deposits are a locally limited phenomenon, it remains unclear whether the relative sea-level changes represent local tectonic or regional events.

Biostratigraphy

Since the earliest descriptions of the presence of Permian fossils at Trogkofel by Geyer (1895, 1898), fossils from "Trogkofel Limestone" were described mostly not from the Trogkofel area, but from various other locations (Schellwien, 1900; Gortani, 1906; Ramovš, 1963, 1968), which later turned out to be older than the Trogkofel Formation. This has contributed to the considerable confusion about the stratigraphic age of the Trogkofel Formation.

In the allodapic rudstones of the local basinal facies at the Zweikofel section (ZK), *Robustoschwagerina spatiosa* was found. Fusulinids are very rare in the actual reef facies of the Trogkofel Formation. Only in the upper part of section TK with the indistinctly bedded limestones, fusulinids, alongside green algae (*Connexia*, *Mizzia*), are occasionally more abundant. However, these are relatively species-poor, specialized communities, including notably frequent *Schubertella paramelonica*, rare *Biwaella* aff. *americana*, and many smaller pseudofusulinids from the group of P. ("*Leeina*") *fusiformis*. The search for conodonts has yielded only a few fragments of *Sweetognathus*, a transitional form to *Neostreptognathodus* and *Diplognathodus triangularis* (=*D. stevensi*?) in the base of the Trogkofel Formation (Forke, 1995, 2002).

In general, a Yakhtashian age (approximately corresponding to the Artinskian) can be assumed for the Trogkofel Formation. However, the stratigraphic extent of the Trogkofel Formation remains uncertain because the faunas occurring in the uppermost parts do not contain significantly younger fusulinid species. In particular, the characteristic forms from the upper Yakhtashian of Central Asia (Leven, 2009), as described in the Goggau Limestone, are absent. In the Goggau Limestone, species of the genera *Pamirina* (*P.* (*Levenella*) *leveni*; *P. darvasica*), *Chalaroschwagerina* aff. *vulgaris*, *Darvasella vulgariformis*, as well as *Darvasites ordinatus*, *Mesoschubertella* spp., and *Minojapanella elongata* occur (Novak and Forke, 2015). *Pseudoreichelina slovenica* is already known from the Zweikofel Formation.

It cannot be ruled out that facies-related reasons are responsible for the absence of the mentioned species in the Trogkofel Formation. While a shelf-edge position is likely for the limestones at Trogkofel/Gartnerkofel, the Goggau Limestone primarily represents deposits of the inner shelf area (Fig. 4). However, due to the lack of well-founded biostratigraphic data, these spatial relationships remain speculative.

The extent to which the Yakhtashian/Bolorian boundary corresponds to the Artinskian/Kungurian boundary is not definitively clarified, as the base of the Kungurian has not yet been ratified in the international stratigraphic scale. Statements regarding the "Kungurian age" of the Trogkofel Formation (Davydov et al., 2013; Schaffhauser et al., 2015; Krainer et al., 2019) are currently considered speculative.

The demise of LPIA

The acme and demise of the Late Palaeozoic Ice Age (LPIA) has long been discussed controversial due to poor control on timings of the glacial/interglacial sequences along the Southern Hemisphere (South America, South Africa, Arabian Peninsula, Australia, and Antarctica). It is now generally accepted that a stepwise deglaciation with repeated returns to glacial conditions at higher latitudes have occurred (Griffis et al., 2019). Recent advances in radioisotope dating, new climate proxies, and astronomical tuning of sequences has improved our understanding of deglaciation events in the Early Permian.

After the early Asselian maximum glaciation, a first deglaciation event occurs around 296 Ma (mid/late Asselian) in the South American Parana Basin, and South African Karoo Basin (Griffis et al., 2019; Cagliari and Schmitz, 2023). This might correspond to a recorded trend from humid to arid climate conditions in the tropical South China slope sediments based on conodont/astronomical tuning (Fang et al., 2021). Late Asselian/Sakmarian is regarded as a return to glacial conditions in higher latitudes of South Africa and Australia. Further cooling/warming events are less well constrained. Several authors have reported on late Sakmarian to early Artinskian (around 290 Ma) warming, indicated by deglaciation in Australia (Fielding et al., 2008; Wang et al., 2023). Further melting in higher latitudinal areas are reported around 282 Ma (early Kungurian) in South Africa and Australia.

However, the causes of the Early Permian stepwise deglaciation and the effects on climate and oceanography in tropical, subtropical, and temperate environments are still poorly understood. Even in the Neogene Ice Age, the teleconnections of glacial/interglacial episodes with climate sensitive factors like prevailing wind directions (upwelling), precipitation (weathering) and hence on the sedimentation in tropical/subtropical environments are still not fully understood (Deik, 2020) (though human society is currently experimenting on this).

Conclusion

Considering the main conclusions of the Carnic Alps stratigraphy in the publication of Calvo-Gonzalez et al. (2023b), a late Asselian age of the Zweikofel Formation based on the conodont biostratigraphy is unsubstantiated and the well-established biostratigraphic correlation based on fusulinids is completely ignored. The difference in cyclic/non-cyclic pattern in sedimentation cannot be accounted to infer the stratigraphic position of the Zottachkopf Formation above the Zweikofel Formation. Instead, further biostratigraphic data are necessary to corroborate the stratigraphic relationships between the two formations. The differences in the amplitude of sea-level changes and mode of cyclicity between the Upper Carboniferous and Lower Permian rocks is generally acknowledged and has been previously mentioned (Samankassou, 1997, Schönlaub and Forke, 2021). A deglaciation event at the Asselian/Sakmarian boundary cannot be deduced from the Carnic Alps stratigraphy.

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Structure of *Vallatisporites* from study of broken specimens

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Introduction

The study of zonate-camerate spores through Transmission Electron Microscopy (TEM) (e.g. Archangelsky and Césari, 1990; Raine et al. 1988) has led to a better understanding of their internal structure and affinities. However TEM is expensive, time consuming, involves concentration on a small number of specimens, and is often inconsistent with practical palynological study which is still overwhelmingly carried out by light microscopy. In this article I show that light microscopy of well-preserved, and particularly of broken specimens, can reveal much about the internal structure of specimens of *Vallatisporites*.

***Vallatisporites*-type spores**

Vallatisporites-type spores are common in the Carboniferous-Permian sedimentary rocks of the Arabian peninsula and are often associated with fluvial or lacustrine glacial facies of the 2165 and OSPZ2 biozones (Penney et al. 2008, Stephenson et al. 2003, Stephenson 2004). The spores are large, often reaching more than 100 microns in diameter. They are trilete, rounded triangular, to almost circular. Their internal and external structure is complex, with grana and spinae on the proximal sides and sometimes complex structures on the distal side that appear to support the zona, perhaps to offer greater strength to the zona, which itself likely had a role in dispersal and perhaps in positioning during germination.

Along with other specimens of the genus *Vallatisporites*, these spores usually have a row of 'pits' or 'intra-zona' vacuoles, with uncertain function, close to the inner margin of the zona. Within the enclosing structure of the spore and zona is an inner body that appears relatively simple and unornamented. This body often does not appear to completely fill the internal cavity of the spore so that a 5 µm or so wide space between the margin of the inner body and the inner margin of spore cavity can be seen when viewed in proximodistal orientation. The concentric position of the inner body within the spore cavity tends to suggest adpression of the exinal layers at the proximal and/or distal poles.

Some of these characters are shown in Fig. 1 which is a very well preserved specimen. However although much can be gained from studying 'perfect' specimens, a lot can also be gained by light microscopy analysis of broken specimens that nevertheless otherwise show aspects of good preservation.

In Fig. 2 a broken specimen that is otherwise quite well preserved shows some of the structural elements better than a complete specimen. This specimen seems to indicate aspects of the inner body and of the margins of the proximal part of the outer spore structure close to the zona. The inner body is clearly punctate rather than completely smooth. It is also quite a bit smaller than the encasing spore body. It appears not to have laesurae (a trilete mark). The proximal part of the outer spore structure close to the zona also seems to be punctate rather than smooth. This layer of exine, besides being punctate, also seems relatively thin and delicate, at least in comparison with the rather rigid zona.

In Fig. 3 another broken specimen, showing an intexinal body that is clearly quite thick walled and punctate is close to being liberated from the spore cavity. The distal exine is seen to be

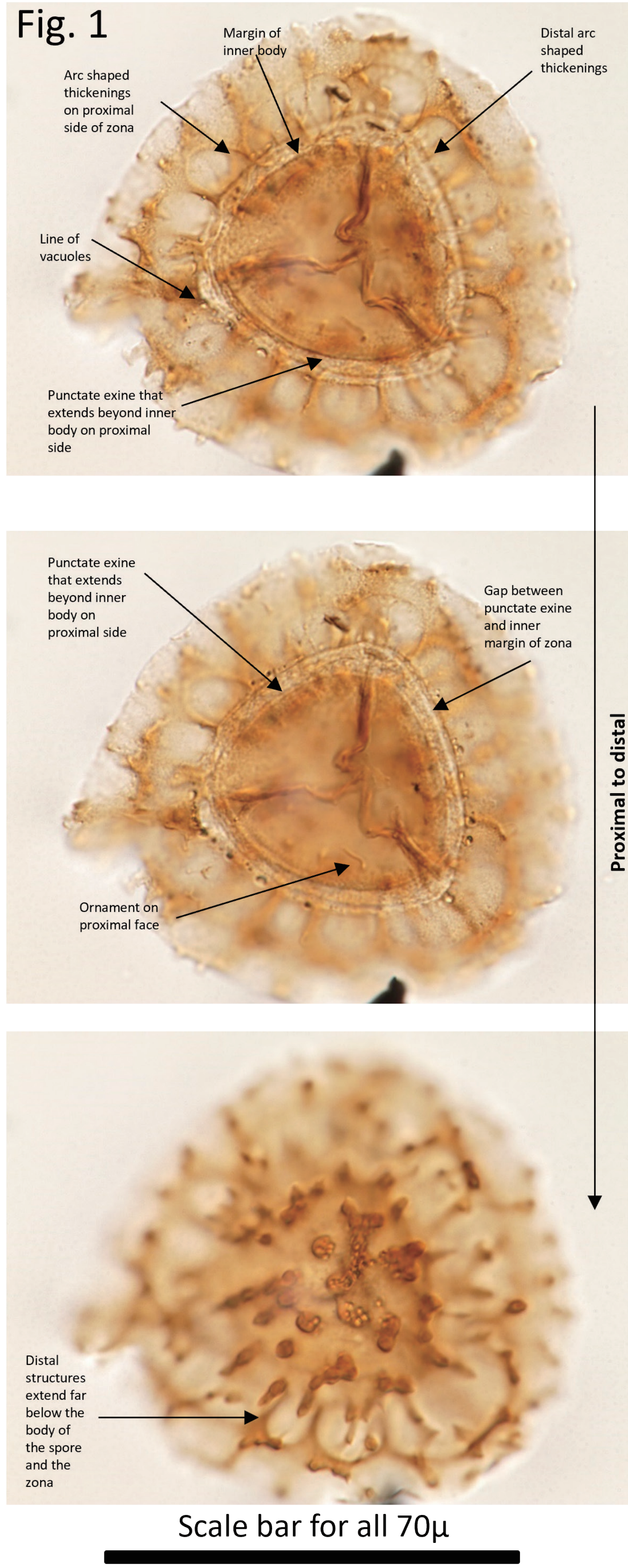
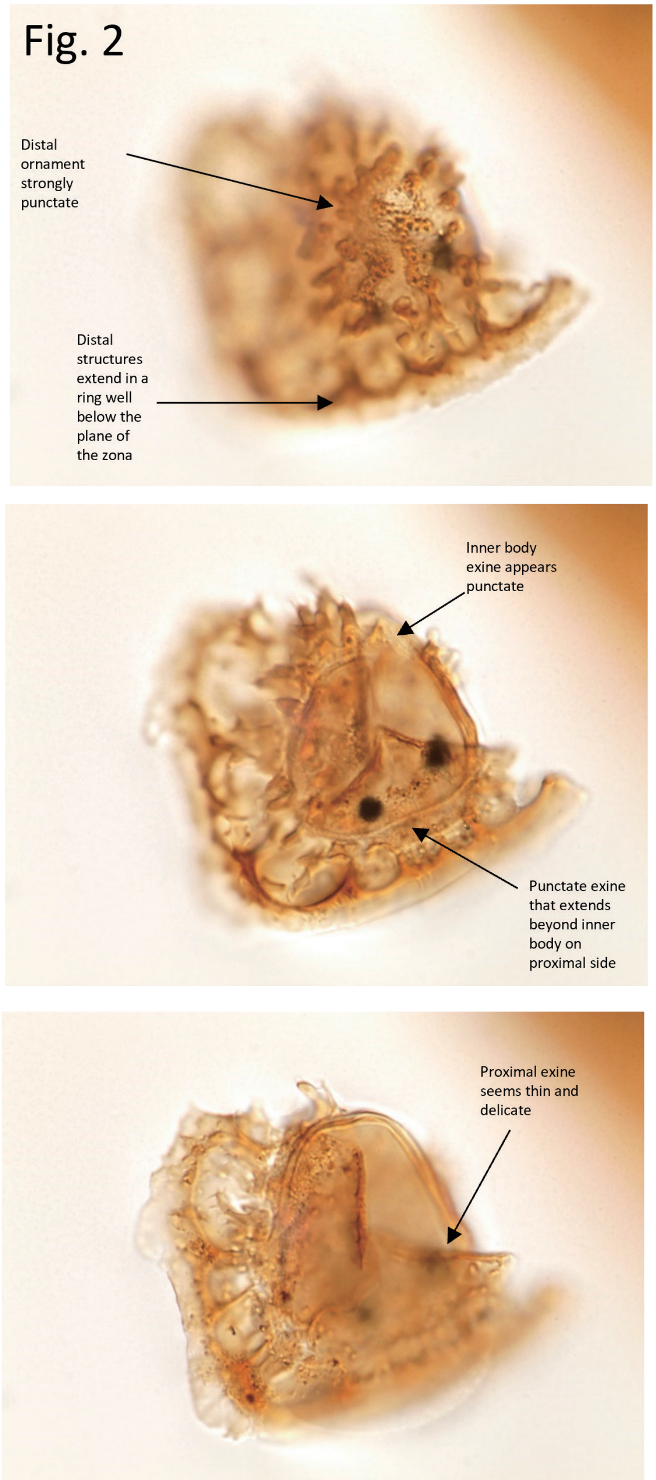
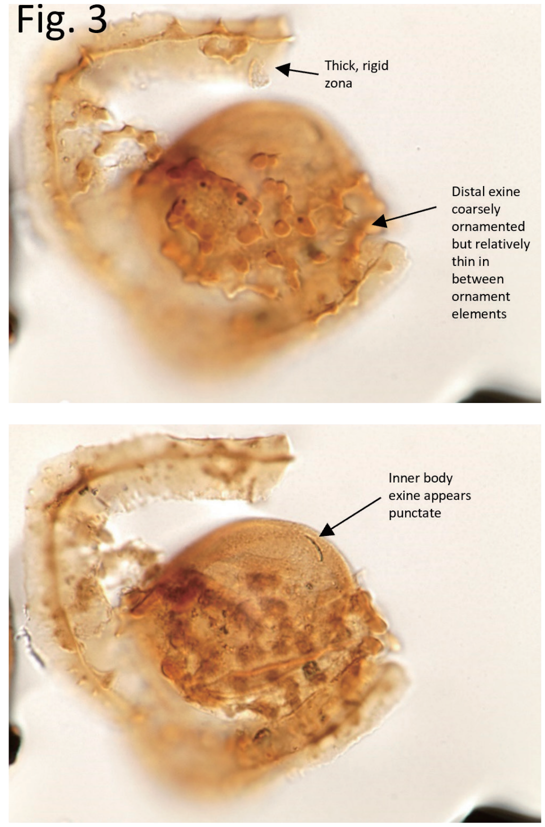


Fig. 1. Complete well-preserved specimen of *Vallatisporites*.



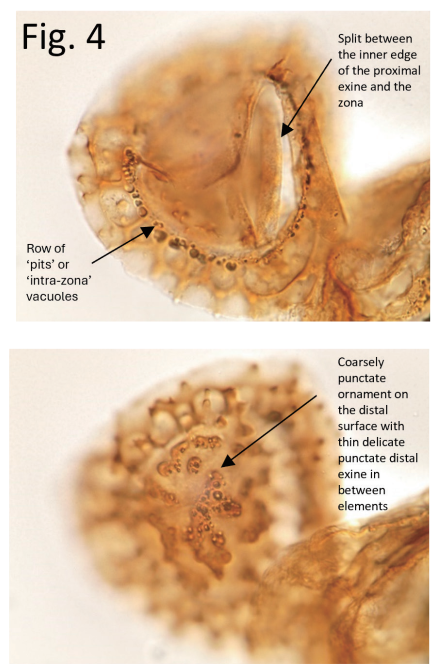
Scale bar for all 70µ

Fig. 2. A broken specimen that is otherwise quite well preserved showing aspects of the inner body, and of the margins of the proximal part of the outer spore structure close to the zona.



Scale bar for all 70µ

Fig. 3 A broken specimen, showing a thick walled and punctate intexinal body.



Scale bar for all 70µ

Fig. 4. A broken specimen, showing a row of 'pits' or 'intra-zona' vacuoles, and very coarsely punctate distal ornament.

Fig. 5 A broken specimen, showing a punctate inner body, and coarsely punctate ornament on the distal surface.

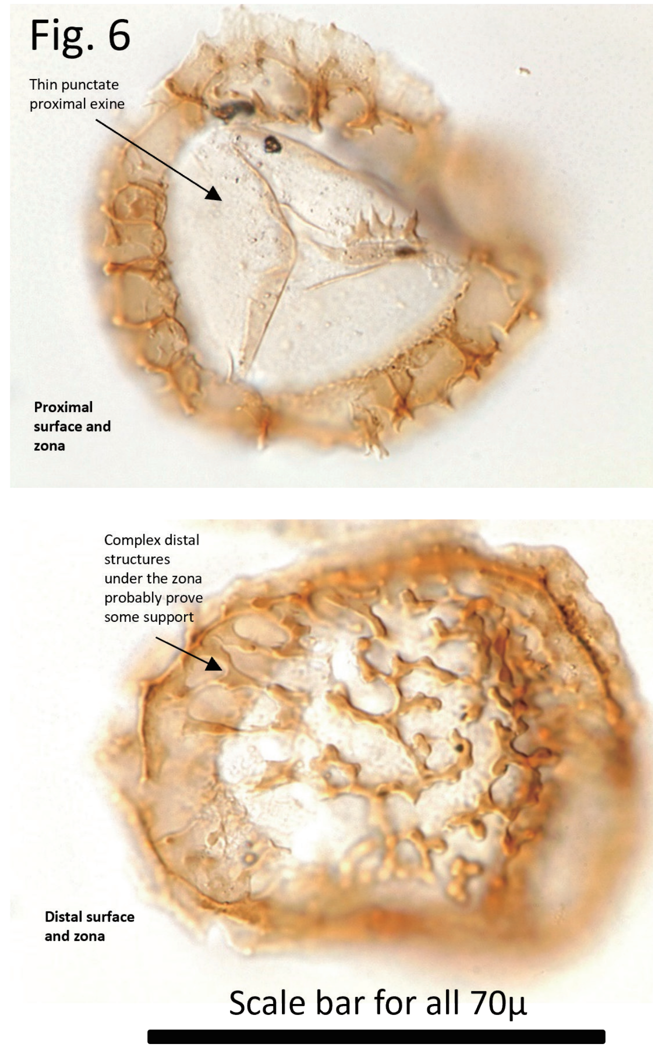


Fig. 6 Parts of *Vallatisporites*-type spores with only the proximal/distal exine and zona

coarsely ornamented but relatively thin in between ornament elements.

Fig. 4 shows an only slightly damaged specimen with a well displayed row of 'pits' or 'intra-zona' vacuoles and a split between the inner edge of the proximal exine and the zona. On the distal surface is very coarsely punctate ornament with thin delicate punctate distal exine in between ornamemt elements. Again the delicacy of this exine, despite the thick ornamentation, will tend to make this part of the spore relatively weak. Fig. 5 again shows a punctate inner body, thin delicate punctate exine that extends beyond inner body on the proximal side, and some coarsely punctate ornament on the distal surface. Perhaps the complex distal structures under the zona seen in this figure, and Fig. 1 provide support to the zona - and structural rigidity - ensuring that spores remained intact for reproductive purposes,

Finally Fig. 6 shows the parts of *Vallatisporites*-type spores with only the proximal exine and zona, and distal exine and zona preserved respectively, so each specimen lacks an intexinal body, and one layer of external exine - proximal or distal. Although not common, these broken specimens allow very detailed study of these different surfaces without the encumbrance of other layers that may obscure detail.

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The Apillapampa section (Bolivia): field trip accomplished in July 2023-a report of "Gondwana to Euramerica Correlations Working Group"

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Introduction

The Permian marine to transitional deposits at Apillapampa in Bolivia matches Permian Stratigraphy Working Group (WG) goals because of co-occurrence of several species of conodonts and fusulinids with abundant other taxa including plants and palynology, as well as volcanic tuffs (some U-Pb dated). 'Bridge taxa' occur throughout different Gondwanan provinces and support correlations with northern hemisphere Cisuralian 'standard sections' (including GSSPs) in Russia, USA, and China (Cisterna et al. 2022, in *Permophiles* 72). As part of an on-going project on Carboniferous – Permian fossiliferous successions of Bolivia (Grader et al., 2008; di Pasquo et al., 2009, 2013, 2014, 2015, 2019, 2022), a field trip to the Apillapampa section was carried out in July 2023.

New data over the last 20 years suggest Asselian and Sakmarian sequences at Apillapampa extend about 100+ m higher into the Sakmarian (vs. previously determined Artinskian ages). This changed regional interpretations of upper Cisuralian strata in Bolivia with many attendant paleontological questions. To further test these data, four of the authors (Mercedes di Pasquo, Gabriela A. Cisterna, Abner Salcedo and Shirley López), went to Apillapampa (Fig. 1) to collect invertebrates and samples for microfossils and palynology. We searched for key Gondwanan taxa among different fossil groups useful for taxonomic revision and regional stratigraphic distribution. We aim to share these data by digital means, including galleries of photographs and taxonomic notes (another aim of the WG), as addressed further below.

Brief geologic and paleontologic notes

The Copacabana Formation crops out along Chulpanimayu Creek at Apillapampa near Cochabamba, west-central Bolivia. Sharp stream bends along strike, and waterfalls, characterize this well exposed Permian section that overlies Devonian rocks at c. 3043 m elevation (17.86669°S, 066.24495°W). The stream was surveyed and the strata were lithostratigraphically described by Chamot (1965), who documented a high-diversity brachiopod fauna in the lower limestones including *Gypospirifer condor*, *Linoproductus cora*, *Waagenoconcha humboldti*, *Kozlowskia capaci* and *Rhipidomella cora*. Grader (2003) tied the Apillapampa section to regional Carboniferous-Permiansequences, later visiting with Iannuzzi and again with Lopez, V. Davidov and C. Henderson in 2007. New mapping, palynology, ash layers dates, plant and marine biostratigraphy were reported by Iannuzzi et al. (2008), Grader et al. (2008); Henderson et al. (2009), di Pasquo and Grader (2012), and di Pasquo et al. (2015, 2019). Copacabana strata lie disconformably over middle Paleozoic rocks, above basal sandstones. Chamot divided the Copacabana Formation into two members: a lower marine member and an upper transitional "coal member," known only in the Cochabamba region, although with correlatives in Peru. Di Pasquo et al. (2015) identified overlying volcaniclastics and silicified mudstones of Permian "Vitiacua Formation" and redefined Copacabana lithosomes and nomenclature. Whereas Chamot's "Coal Member" started at ~195 m above the base of basal sandstones (0 m), we have re-defined the coal member as bounded by sequence boundaries between 242 m to 310 m - both intervals that crop out at major waterfalls.

The marine lower Copacabana strata yielded conodonts (*Neostreptognathous pequopensis* - *Sweetognathodus behnkeni* Assemblage Zone), small foraminifers (*Frontinodosaria-Robuloides*), and fusulinids (*Eoparafusulina gracilus* Subzone), and other invertebrates such as crinoids, bryozoans, coral, brachiopods, bivalves, gastropods that are shelfal marine deposits (Chamot, 1965; Suárez-Riglos et al., 1987; Dalenz and Merino, 1994, see these references in Grader et al., 2008; di Pasquo et al., 2015, 2019). Figure 1 shows a 33 m interval of shaley, fossiliferous distal ramp turbidites - "Apillapampa facies" - that were originally broadly correlated by Grader (2003) above a regional Artinskian sea level rise with high-energy fusulinid platform shoals ("Huarina-Yaco" facies). Like all the Copacabana sections in Bolivia, abundant airfall tuffs occur throughout the Apillapampa section within a relatively deep-water marine association as well as higher in the section in the carbonaceous shales and swamp environments of the "Coal Member". For example, the thick sandy tephra unit at 120 m (Fig. 1.A), overlies a resistant fossiliferous mudstone unit with abundant *Zoophycos* sp., and is overlain by thin to medium-bedded limestone beds and laminated to bioturbated dark shale.

The Upper Coal member overlies marine Copacabana strata and is here at Apillapampa, broken into four new lithosomes, including discovery of 45 m of uppermost volcaniclastics and silicified mudstones that share facies with the Vitiacua Formation located in southern Bolivia (cf. Grader et al., 2008; di Pasquo et al., 2019). Carbonaceous shale with lycopods and a tuffaceous bed overly a prominent cherty laminated dolostone at 242 m. This is the base of the sandy, shaley, coal-bearing lithotope ("coal member" sensu di Pasquo et al., 2015) and suggests significant basinward shift of depositional environments. Plant remains are mostly related to lycophytes and pteridophytes (*Dizeugotheca branisae*, *Pecopteris* sp.), and one new sphenophyte (Chamot, 1965; Iannuzzi et al., 2008; see these references in Grader et al., 2008). Cousminer (1965) described 30 species of palynomorphs from six samples in the Coal Member, and found that 64% of the palynomorph assemblage was composed of pteridophytes, and 21% were gymnosperm pollen grains. An updated list of Cousminer´s palynotaxa can be found in Pasquo and Grader (2012).

In 2007, two field trips were carried out by different researchers guided by George Grader, and samples were extracted for multidisciplinary studies (palynology, paleobotany, microfossils, and geochemistry and isotopic analyses).

CA-ID-TIMS radiometric dates from volcanic ash beds within the section were first cited by Henderson et al. (2009) as 298 Ma (40 m), 295.2 Ma (120 m), 293.3 Ma (154 m), 293 Ma (185 m), and 291.6 Ma (242 m). This suggested that the lower marine to transitional strata are Asselian to Sakmarian and most of the coal member above 247 m sensu di Pasquo et al. (2015) is probably Artinskian. However, the precision of zircon dating performed at Boise State University by Jim Crowley and Mark Schmitz, should be reanalysed using current tracers and statistical protocols that have not been published yet. The presence of the conodont *Sweetognathus* cf. *obliquidentatus* at 132 m in the marine lower Copacabana rocks corroborates with a Sakmarian correlation. *Sweetognathus whitei* and *Sw.* aff. *behnkeni* and the fusulinid *Eoparafusulina linearis* occur lower in the section as well, which are typical of the late Asselian and early Sakmarian (Henderson, 2018; Petryshen et al., 2020; Chernykh et al., 2022 in *Permophiles* 72). The presence of these key taxa in this Cisuralian succession was the main reason for making the proposal to the SPS Working Group for considering it a key Gondwanan section (see Cisterna et al. 2022 in *Permophiles* 73).

Twelve shale samples collected for palynology were processed and studied by M. di Pasquo in 2009. They yielded 92 spores, pollen and other taxa and their quantitative taxonomic and stratigraphic distribution published by di Pasquo et al. (2009), di Pasquo and Grader (2012) and di Pasquo et al. (2022). The biostratigraphic proposal of informal palynozones *Vittatina costabilis* and *Lueckisporites virkkiae* of Early Permian age established by di Pasquo and Grader (2012), composed of gymnosperms (coniferaleans, cordaitaleans, and pteridosperm-like plants), with significant contributions from lower vascular plants (variably pteridophytes, sphenophylls and lycophytes). These palynoassemblages were based on the first appearance of some key taxa, especially those aforementioned, and compared and correlated with palynozones of South America and elsewhere by di Pasquo et al. (2013, 2014, and 2015). Plates with illustrations of palynomorphs are included in di Pasquo et al. (2015, 2022). Hence, the lower assemblage was correlated with the South American *Vittatina costabilis* (VcZ) Souza, *Pakhapites fusus-Vittatina subsaccata* (FSZ) Césari and

Gutiérrez, *Cristatisporites inconstans-Vittatina subsaccata* (ISZ) Beri et al. palynozones due to the presence of species such as *Converrucosporites confluens*, *Polypodiisporites mutabilis* and, *Lunatisporites pellucidus*.

The upper assemblages correlated to the *Lueckisporites virkkiae* (LvZ) Souza, *Lueckisporites-Weylandites* (LWZ) Césari and Gutiérrez, and *Striatoabieites anaverrucosus-Staurosaccites cordubensis* (ACZ) biozones (e.g. *Lueckisporites virkkiae*, *Lunatisporites acutus*, *Protohaploxypinus samoilovichii*, *Thymospora criciumensis*, *T. rugulosa*, and *Convolutispora uruguaiensis*).

Considering the five isotopically- dated volcanic ash layers that constrained the lower member of Copacabana Formation and part of the overlying "Coal Member" (sensu Chamot, 1965) as Asselian and Sakmarian through probably Artinskian (see Henderson et al., 2009, and di Pasquo and Grader, 2012), di Pasquo et al. (2015) discussed the disagreement between a late Asselian FAD age of *Lueckisporites virkkiae*, and the mid- Artinskian documented in Brazil, Uruguay, Precordillera Argentina and elsewhere in Africa, Australia, Oman, and Saudi Arabia, also radiometrically- constrained. Particularly in the Paraná Basin of Brazil, Boardman et al. (2012a, 2012b) reported the presence of *Lueckisporites virkkiae* in the Faxinal Coal Field (Rio Bonito Formation), where radiometric dating

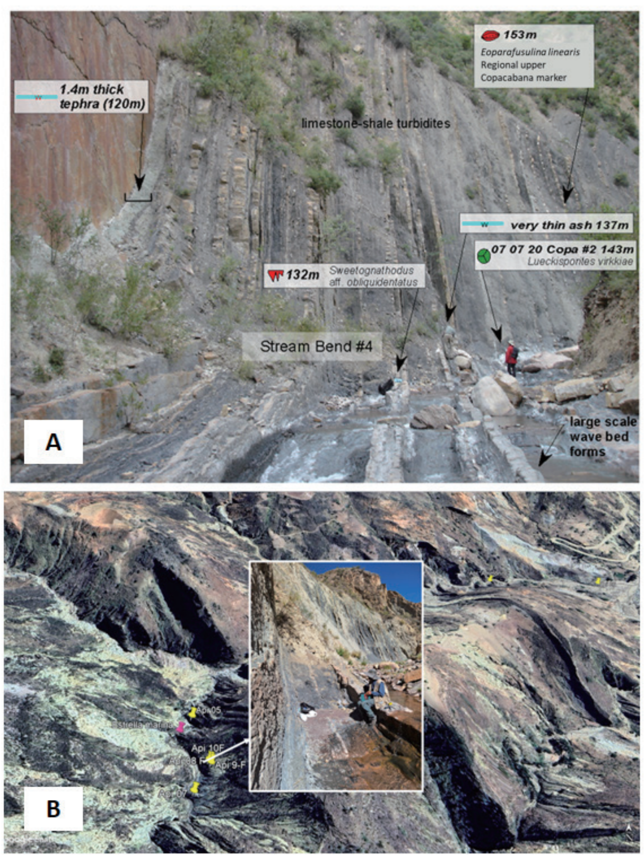

Fig. 1. A. Apillapampa outcrop at Quebrada Chullpanimayo showing vertically bedded, fossiliferous limestone and shale of the Lower Copacabana Member. Photograph taken during medium water level, March 2007. Up-section is to the right; person for scale (see di Pasquo et al., 2015, included in Cisterna et al., 2022). B. The picture corresponds to the same place (120 m) over the Google map image both taken in 2023.

suggests a late Sakmarian- early Artinskian age (see Souza et al., 2021). Therefore, whether the radiometric data are correct, Bolivia would have been an older center of dispersion for some striate and taeniate pollen grains and monolete spores since the Asselian, including *Lueckisporites virkkiae*. The relationship between the palynofloral evolution and near-field glaciation and deglaciation as likely responsible for migration of plants throughout Gondwana was the explanation given by di Pasquo et al. (2015, 2019). The plant assemblages akin to the *Glossopteris* Flora (e.g. lycophytes and pecopterids) documented in the coal beds of the Copacabana Formation at Apillapampa are part of the records of this long-ranged flora in South America and elsewhere in Gondwana (Rischbieter et al., 2022; Kavali et al., 2022). An approach to climatic and paleogeographic changes reflected by provincialism during the Asselian-Sakmarian to Late Permian is addressed by di Pasquo et al. (2022). Actually, as this disagreement has not been refuted or confirmed and, globally, Lower Permian palynoassemblages mostly shared long- ranged taxa and those key taxa exhibit diachronic ranges, therefore, the precise stratigraphic location of microfossil markers aforementioned, along with the ranges of key palynomorph and a detail taxonomy of brachiopods is mandatory for a correlation with paleo-equatorial successions.

Notes on Field trip 2023

The new sampling carried out in the recent field trip will allow a revision of palynotaxa appearances along with a detailed study of the associated invertebrates, which are now part of a taxonomic study to find out potential bridge-taxa, focused on the presence of cosmopolitan and endemic species, and the updating of their age ranges. It will also allow the recognition of global diachronism among key species.

We expect to establish accurate regional and global correlations based on our new collection of fossils from 2024. The new updates of ages based on conodont and fusulinid taxa globally, and the reanalysis of radiometric data from Apillapampa will be published. In addition, a local biostratigraphic scheme based on palynomorphs, as preliminary proposed by di Pasquo et al. (2014), is required for the Permian of Bolivia and Peru. Furthermore, a proposal of brachiopod zones is needed, after revision of key species such as *Gypospirifer condor*, *Linoproductus cora*, *Waagenoconcha humboldti*, *Kozlowskia capaci* and *Rhipidomella cora*, among others takes place. These will be useful for biostratigraphic correlations in South America, i.e. Bolivia, Perú and north-central Chile (Cisterna et al., 2014; Cisterna and Sterren, 2022). On the other hand, preliminary quantitative studies of the brachiopod assemblages recorded at different latitudes of the Pennsylvanian-Cisuralian platform of western South America, suggest significant variations in terms of composition and diversity (Halpern et al., 2018). In this context, a better taxonomic knowledge of the brachiopods from the Apillapampa section can contribute to understanding the diversity patterns along the latitude gradient in this carbonate platform.

Preliminary comparison with the Usolka section (URSS)

A palynological comparison between the sections “Usolka and Apillapampa” was attempted by MDP with the aim of identifying "potential palynomorphs as bridge-taxa"and presented in Meeting of the WG Gondwana to Euramerica correlations held in March 17, 2023. Illustrated palynomorphs published by di Pasquo et al. (2015, 2022) and the images included in Chernykh et al. (2022) and those uploaded by Stephenson in 2023 in the virtual gallery (https://permian.stratigraphy.org//Gallery/Usolka) were considered (see also Stephenson, 2016, 2017). Particularly, the Dal'ny Tulkas section proposed as a candidate for the reference section of the Artinskian Stage and ratified as the GSSP for the Sakmarian in 2020 (see Chernykh et al., 2020, 2021). Comments published in *Permophiles* 72 (2022) and also, in *Permophiles* 73 (Horacek, 2022) are out of the scope of this contribution. Chernykh et al. (2022) documented a complete paleontological record for three key Permian biostratigraphic groups of microfossils (conodonts, ammonoids, and foraminifers), as well as macrobiota (e.g. brachiopods, fishes), and plant remains and palynomorphs. The lower boundary of the Artinskian Stage was located at 0.6 m above the base of bed 4b in Dal'ny Tulkas section due to the record of the FAD of the marker species *Sweetognathus asymmetricus* in the continuous phylogenetic lineage of development of *Sweetognathus expansus - Sw. aff. merrilli - Sw. binodosus - Sw. anceps - Sw. asymmetricus* (see Henderson et al., 2019; Henderson, 2018). Geochronologic ages of zircons interpolated between 290.1 Ma ± 0.2 Ma and 290.5 Ma ± 0.4 Ma (Sakmarian), and many additional fossils groups, particularly ammonoids and fusulines, serve as additional markers to correlate the boundary. This information and that one from the Apillapampa section will enable to make correlations between different fossil groups of Cisuralian successions in both Gondwanan and northern hemisphere regions, also supported by radiometric ages.

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Stratigraphy of the Early Permian Bromacker locality (Tambach Formation, Sakmarian, Germany)

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The Early Permian Bromacker locality of central Germany (near the village of Tambach-Dietharz, Thuringia) yielded one of the most important tetrapod associations of this time interval as regards diversity and preservation, consisting of both skeletons and footprints (e.g., Lucas, 2018; Voigt and Lucas, 2018). So, it is important to know a precise age for this site. Unfortunately, radiometric ages are not available within the Tambach Formation, but its fossil content can be used for a reliable biostratigraphy, which can be combined with the recent radiometric ages on underlying formations (Lützner et al., 2021). The Bromacker locality belongs to the Tambach Sandstone Member of the Tambach Formation, consisting of typical fluvial red beds. At this locality, the succession is exposed for about 10 m and consists of tabular to cross-stratified sandstone beds interbedded with thin laminated mudstone horizons, passing upwards to cross-stratified fine-grained sandstone and laminated thin mudstone layers (Eberth et al., 2000).

Tetrapod footprints, known since the 19th century because of quarrying activities, include exceptionally-preserved and long trackways, mostly preserved in convex hyporelief on the bottom of sandstone beds (e.g., Voigt and Haubold, 2000; Marchetti et al., 2020). The ichnoassociation includes the ichnogenera *Ichniotherium* (diadectomorphs), *Amphisauropus* (seymouriamorphs), *Dimetropus* (non-therapsid synapsids), *Notalacerta* (captorhinomorphs), *Varanopus* (bolosaurian parareptiles), and *Tambachichnium* (varanopids). New research part of the BMBF funded project Bromacker 2020-2025 highlights the additional occurrences of the ichnogenera cf. *Batrachichnus* and *Limnopus* (temnospondyls) and *Dromopus* (araeoscelid or varanopid). This is an ichnoassociation typical of the Kasimovian-early Artinskian *Dromopus* footprint biochron (e.g., Voigt and Lucas, 2018; Schneider et al., 2020; Lucas et al., 2022).

Tetrapod skeletons, first found in 1974 (Martens et al., 1981), include a diverse association with several well-preserved, articulated and nearly complete skeletons, coming mainly from two distinct horizons in the upper part of the Bromacker succession (e.g., Eberth et al., 2000; MacDougall et al., 2022). The anamniotes include the diadectids *Diadectes* and *Orobates*, the seymouriamorph *Seymouria*, the trematopids *Rotaryus* and *Tambachia* and the amphibamid *Georgenthalia*. The synapsids include the sphenacodont *Dimetrodon* and the caseid *Martensius*. The reptiles include the captorhinormorph *Thuringothyris* and the bolosaurid *Eudibamus*. The varanopids include *Tambacarnifex*. The nearby locality of Tambach-Dietharz, belonging to the same formation, yielded the ostodolepid recumbirostran *Tambaroter*. This is a typical association of the Seymouran Land Vertebrate Faunachron (LVF), based on the associations of the upper Archer City (‘Nocona’) and Petrolia formations of Texas (Lucas, 2018). The base of the upper Archer City Formation is correlated with the Coleman Junction Limestone, recently dated with conodonts as base Sakmarian (Henderson and Read, 2023). The base of the Petrolia Formation is correlated with the Elm Creek Limestone, recently dated with conodonts as Sakmarian (Henderson and Read, 2023). The only tetrapod species found in the Tambach Formation in common with the North American associations is *Seymouria sanjuanensis* (Berman and Martens, 1993; Berman et al., 2000), found also in the late Wolfcampian Organ Rock Shale of Utah (Berman et al., 1987) and in the middle Wolfcampian upper Arroyo del Agua Formation of New Mexico (Lucas et al., 2005). Both these units were considered Seymouran, based on the tetrapod associations (Lucas, 2018). Therefore, the tetrapod association from the Tambach Formation suggests a Sakmarian age for this unit.

The insect association of the Bromacker locality comes from laminated mudstones and includes the *Moravamylacris kukalovae* Assemblage Zone (Schneider and Werneburg, 2012). This association is found also in the Standenbuhl Formation of the Saar-Nahe Basin, Germany, which is no younger than the early Artinskian because it includes a tetrapod ichnoassociation assignable to the *Dromopus* footprint biochron (Voigt, 2012). Also, it occurs in the upper Letovice Formation, right above some levels correlated with Asselian fish associations (Stamberg, 2014). Therefore, the insect association suggests a late Asselian-early Artinskian age for the Tambach Formation.

The conchostracan association from the Bromacker locality is preserved in laminated mudstones and is generally assigned to the Wilhelmsthal assemblage zone, but some forms are similar to the underlying Oberhof assemblage zone, suggesting a general early Permian age (Schneider et al., 2020). Martens (2020) suggested the possible occurrence of *Lioestheria monticula*, a species found in the Tambach Formation, in the lower-middle Archer City Formation of Texas, of late Asselian-early Sakmarian age according to the latest conodont studies (Henderson and Read, 2023). Martens and Lucas (2005) described material similar to *L. monticula* also from the Abo Formation of New Mexico, assigned to a Wolfcampian, and so, early Cisuralian age (Lucas et al., 1999). A further possible occurrence is from the early Cisuralian Bleichenbach Formation of Germany (Martens, 2020). Waiting for a revision, conchostracan data are in general agreement with an early Cisuralian age for the Tambach Formation.

Radiometric datings (U–Pb CA–ID–TIMS) on volcanic rocks within the Rotterode Formation, directly underlying the Tambach Formation, indicate a late Asselian age (295.8±0.4 Ma; Lützner et al., 2021). Considering the unconformity at the base of Tambach Formation, the maximum age for this unit is probably latest Asselian.

So, the age of the Tambach Formation inferred from tetrapod faunas and ichnofaunas is consistent with invertebrate biostratigraphy and radioisotopic ages and can be currently estimated as Sakmarian. The age of the Tambach Formation is thus relatively well constrained, and this is of the outmost importance for a correct evaluation of some key events in the tetrapod evolution registered in this unit.

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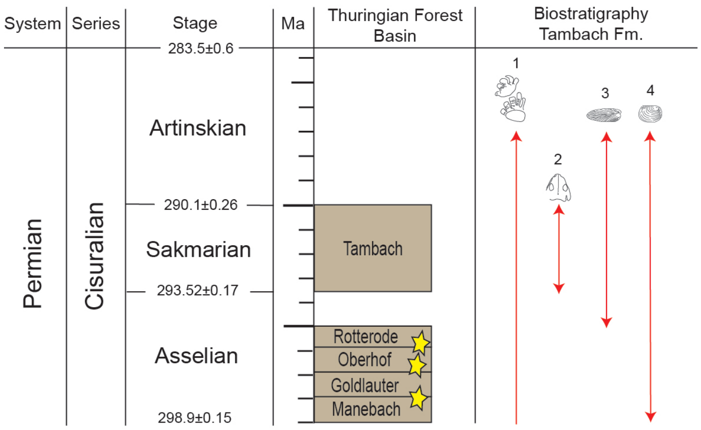

Fig. 1. Chronostratigraphic chart with the early Cisuralian formations from the Thuringian Forest Basin and the biostratigaphic ranges of significant fossils from the Tambach Formation. 1. tetrapod footprints; 2. tetrapod skeletons; 3. insects; 4. conchostracans. 3 and 4 redrawn from Schneider et al. (2020). Stars indicate radiometric ages after Lützner et al. (2021).

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The crises in the global Permian correlation - Canadian Arctic-Urals case

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Significant progress has been reached in the Permian biostratigraphy and chronostratigraphy in the last couple of decades thanks to the new conodont and fusulinid studies in many regions: in the Arctic, Russian Platform and Urals, Carnic Alps, Central Asia, North America, Turkey, Japan, and China. Besides, developing the radioisotopic method (CA-IDTIMS) greatly influenced global biostratigraphy and chronostratigraphy. The International Permian Time scale is nearly complete with only one Kungurian Stage left unestablished. However, the global Permian correlation remains a challenging puzzle to solve. Moreover, the correlation is getting controversial, and a crisis is currently occurring on this topic. The correlation could be improved with the high-precision (CA-IDTIMS) radioisotopic dates that were obtained from the type-sections in the Urals (Cisuralian), Texas (Guadalupian), and South China (Lopingian). Still, this method is not readily available due to a limited number of labs and facilities and because it is relatively expensive. Moreover, sometimes the application of the CA-IDTIMS method increases the correlation problems and stimulates discussion and controversies that would have been hard to expect in the recent past (Henderson, 2018).

A set of papers focusing on late Paleozoic biostratigraphy, sequence stratigraphy, chronostratigraphy, and global correlation in the Canadian Arctic, North America, and the Carnic Alps was published last year (Beauchamp et al., 2022a, 2022b; González et al. 2022). The primary objective of these papers was to establish a sequence stratigraphic pattern driven either by local tectonism, global eustacy, or a combination of both. Biostratigraphy and chronostratigraphy played pivotal roles in aligning the established lithostratigraphic sequences with the time scale.

The correlations proposed in these publications significantly deviate from previously established frameworks, particularly those suggested in fusulinid and conodont studies by some researchers (Wardlaw and Davydov 2000; Boardman II et al. 2009). The former correlation of the upper Paleozoic in the Canadian Arctic was generally in line with fusulinid biostratigraphy (Harker and Thorsteinsson 1960; Nassichuk and Wilde 1977; Davydov 1991; Chuvashov 1993; Beauchamp and Henderson 1994; Rui Lin et al. 1994), has undergone substantial changes in the current research (Beauchamp et al. 2022a). These recent findings are inconsistent with the previously accepted correlations, leading to a notable shift in our understanding of the region's geological history.

The redefinition of the Sakmarian base (Chernykh et al., 2020) has brought about a significant shift in correlation across various regions. Initially proposed at 51.4 meters above the base (mab) in the Usolka section, associated with the FOD of *Mesogondolella uralensis* (Schmitz & Davydov, 2012; Chernykh et al., 2016), this boundary coincided with the traditional position in the Kondurovsky section near the base of the Karamurun Formation (20 meters above the formation's base). At this level, it aligned with the FOD of the fusulinid species *Sakmarella moelleri* (Rauser-Chernousova, 1965; Davydov et al., 2005).

However, the boundary position was subsequently revised, moving upwards to the FOD (first occurrence datum) of the species *Mesogondolella monstra*, positioned at 55.4 meters above the base in the Usolka sections (Chernykh et al., 2020). The main rationale for this redefinition was the assertion that *Mesogondolella uralensis* "has not been known from outside of the southern Urals" (Henderson et al., 2017), which has proven inaccurate. Bruce Wardlaw identified *Mesogondolella uralensis* near the base of the Darwin Canyon Formation in the Marble Canyon Area, Eastern California (Stone et al., 2014), and Valery Chernykh (personal communication, 2015) identified the species in the lower Carbon Ridge Fm. at Secret Canyon, Nevada (data from the thesis of BSU student Wang Dechin).

Despite the potential associated with the *Mesogondolella uralensis* FOD that retains a traditional boundary in the International Geologic Time Scale (IGTS). Instead, the new boundary and the Global Stratotype Section and Point (GSSP) were proposed at 55.4 mab in the Usolka section, aligned with the FOD of *Mesogondolella monstra*. This species was selected due to its documented occurrence in the Canadian Arctic, Nevada, Central Iran, and Thailand (Beauchamp et al. 2022b; Beauchamp et al. 2022a). Concerns about significant changes to the Asselian-Sakmarian timescale and the need for a new global correlation were dismissed. The redefined Sakmarian base shortens the Sakmarian by 1.5 million years, consequently lengthening the Asselian Stage and creating a disparity between the Asselian and Sakmarian stages. The durations of the Asselian and Sakmarian are now inverted compared to previous estimates: 3.4 vs 5.5 Myrs in 2012 versus 3.0 vs 5.4 Myrs in 2020 (Henderson et al. 2012; Henderson and Shen 2020). This also implies that a significant portion of the lower Sakmarian (sensu lato) (most of the Tastubian Regional stage in the Urals) now falls within the Asselian age range, and the Sakmarian-Artinskian boundary is now positioned somewhere within the upper Tastubian.

The exact location of this boundary in the Urals and surrounding regions must be a matter of concern for the Permian Commission of Russia. However, referring to the lower Sakmarian as Tastubian is inaccurate (Henderson and Shen 2020; Fielding et al. 2023), because the base of the Sakmarian Stage now occurs in the upper Tastubian Regional stage of the Urals. Therefore, this unit must be replaced, as outlined in sections 3.B.4 at https://stratigraphy.org/guide and Zhamoida (2006). It is suspected that those adopting the term "Tastubian" in the new chronostratigraphic context were not aware of these complexities. Evidently, a new global-wide correlation of the boundary would be required as we have a new Sakmarian (*sensu stricto*) stage, the base of which is much younger and therefore higher in the stratigraphic sections and chronostratigraphy of many regional and global events must be reconsidered. One example is the early Sakmarian global glacial event in Parana Basin, Brazil, Karoo Basin in South Africa, and in the Nangetty and Lyons formations in west Australia, which now become late Asselian (Haig et al. 2014; Griffis et al. 2019). Consequently, the chronostratigraphic correlation of the global and regional eustasy pattern must be changed as well.

The conodont study in the Arctic has traditionally supported fusulinid-based correlation methods (Harker and Thorsteinsson, 1960; Nassichuk and Wilde, 1977; Henderson, 1988; Nassichuk and Lin, 1992; Chuvashov, 1993; Beauchamp and Henderson, 1994). However, a significant shift in correlation occurred following the acquisition of radioisotopic dates from the Appilapampa section in Bolivia, never published, but somehow distributed within the scientific community (Henderson et al., 2009). These dates led to the reassessment of the conodonts *Sweetognathus merrilli* and *Sw. whitei* as being of Asselian age, prompting a substantial alteration in correlation across the Arctic, entire North America, and the Carnic Alps.

Regrettably, the conodont assemblages in Bolivia, despite being mentioned in my communication with Prof. Henderson (April 2008) where he mentioned *Sweetognathus behnkeni* and *Neostreptognathodus pequopensis* at 156.5 meters in the Appilapampa section were noted, have never been formally published except for a brief abstract. Notably, in the abstract (Henderson et al., 2009), these two species were not reported. While acknowledging that the data in the abstract were preliminary determinations, the absence of such characteristic species raises uncertainties about conodont species distribution, their age, and the rationale behind the correlation shift. Consequently, until comprehensive conodont data from the

Appilapampa section in Bolivia are officially published, a thorough understanding of the distribution, age, and reasons for the conodont species' presence or absence remains elusive.

Since then, two groups of species, namely *Sweetognathus merrilli* and *Sw. whitei* in North America (including the Canadian Arctic), and *Sweetognathus "merrilli"* and *Sw. "whitei"* in the rest of the world, were proposed (Henderson, 2018). A hypothesis was formulated suggesting that these two homeomorphic groups evolved independently, and developed in North America during the Asselian, and in the Urals and other regions during the Sakmarian and Artinskian. A dedicated study on the conodont morphospace was conducted to distinguish the differences between these groups (Petryshen et al., 2020). While geometric morphometric techniques proved to be a valuable tool, the absence of a crucial ontogeny study hinders our ability to recognize the evolutionary and morphological differences and parallelisms in these two hypothetical phylogenetic lineages, given the inherent challenges presented by the conodonts' nature (the teeth of an unobserved animal). Furthermore, the practicality of this study and its applicability in routine work remain unclear. Questions linger regarding how other researchers can effectively separate these groups without the benefit of geometric morphometric techniques.

The late Paleozoic fauna and sedimentation patterns in the Urals, Timan-Pechora, Spitsbergen, North Greenland, Barents Sea, Canadian Arctic, and Alaska, collectively known as the Boreal province, exhibit numerous common traits and shared taxa of conodonts and fusulinids across these regions, with only a few local or endemic forms. Correlating the upper Paleozoic among these regions has never posed a significant challenge, as fusulinids have been a reliable tool, and the fusulinid successions in these areas are generally consistent (Ross and Dunbar, 1962; Rauser-Chernousova, 1965; Petocz, 1970; Nassichuk and Wilde, 1977; Davydov, 1991; Konovalova, 1991; Nilsson et al., 1991; Nassichuk and Lin, 1992; Chuvashov, 1993; Davydov et al., 1994; Groves et al., 1994; Wahlman et al., 1995; Nilsson and Davydov, 1997; Davydov et al., 2001). The fusulinid and conodont successions in the Urals were calibrated with radioisotopic dates (Schmitz and Davydov, 2012). In a recent publication from the Canadian Arctic, numerous reported fusulinid species include many Uralian taxa (Beauchamp et al., 2022). However, their age and relationship with conodonts differ significantly from what is known in the Urals and other Arctic regions.

Here are the analyses of the fusulinids reported in the Canadian Arctic succession, referred to as Gzhelian-Asselian (Beauchamp et al., 2002, fig. 10B). This interval is divided into sequences G1-G12 and A1-A14, and these units are used as operational units (Fig. 1). Sequence G1 is characterized by *Rauserites variabilis* (Rosovskaya, 1950) and *R.* ex gr. *paraarcticus* (Rauser, 1938), which are typical fusulinids for the early Gzhelian in the Russian Platform and Urals (Rosovskaya, 1958; Schmitz and Davydov, 2012).

The next assemblage from sequence G9 includes prominent fusulinids such as *Daixina vasilkovskyi* (Bensh, 1962), *D. sokensis* (Rauser, 1938), *Schellwienia krushiensis* (Alksne, 1976), and *Sch.* ex gr. *arctica* (Schwllwien, 1908), characteristic of the late Gzhelian *Daixina sokensis* zone in the Russian Platform, Urals, Spitsbergen, Barents Sea, and North Greenland (Schellwien, 1909; Rosovskaya, 1958; Davydov et al., 1992; Nilsson and Davydov, 1997; Ehrenberg et al., 2000; Davydov et al., 2001).

Sequence G12 is characterized by *Pseudofusulina justa* (Konovalova, 1991), *Ps. rosovskayae* (Konovalova, 1962), and *Daixina amdrupensis* (Ross and Dunbar, 1962). The first two species are described from the uppermost Gzhelian (*Schwagerina robusta* zone) and lower Asselian (*Sphaeroschwagerina fusiformis* zone) in the Timan-Pechota Basin (Volozhanina, 1962; Konovalova, 1991). *Schellwienia amdrupensis* is described from the upper Marine Group, Amdrup Land, Greenland, and ranges from the upper Gzhelian to lower Asselian (Ross and Dunbar, 1962; Nilsson, 1994).

Sequence A1, inclusive of species spanning from the Gzhelian, comprises *Schwagerina aquilonae* (Konovalova, 1962), *Sch.* aff. *biconica* (Scherbovich, 1958), *Pseudofusulina jurjachansis* (Konovalova, 1991), *Sphaeroschwagerina* sp., and *Sakmarella blochini* (Korzhenevsky, 1940). This assemblage appears mixed, featuring species known from lower Asselian (*Ps. jurjachansis*) through upper Tastubian (*Sakmarella blochini*), which, in the Urals, Timan-Pechora, Barent Sea, and Spitsbergen, do not typically co-occur. *Schwagerina* aff. *biconica* and *Sakmarella blochini* are present in rocks that now belong to the latest Asselian (*sensu lato*) and lower Sakmarian (*sensu stricto*) (Fig. 1), i.e., in the Tastubian of the Urals. The assemblage's taxonomic uncertainty is likely, and it is challenging to anticipate the reworking nature of the assemblage in the carbonate facies. The dominance of *Sakmarella* and advanced *Schwagerina* in Sequence A1 suggests its most probable Shikhanian - upper Tastubian age (latest Asselian sensu lato, to early Sakmarian sensu stricto). This implies a gap between G12 and A1 sequences, with the early and middle Asselian missing. This is consistent with gaps in the platform setting at this time in Greenland, Spitsbergen, and Timan (Nilsson, 1994; Davydov et al., 1999; Davydov et al., 2001; Remizova, 2004) and an early-middle Asselian glacial event in South Africa and South America (Griffis et al., 2019).

The next significant fusulinid assemblage is documented from Sequence A4-A7 (Beauchamp et al., 2022). It includes *Schwagerina whartoni* Petocz, 1970, *Schw. nathorsti* (Schellwien, 1908), *Schw. rowetti* Petocz, 1970, *Schw.* aff. *pseudokaragasensis* Petocz, 1970, *Schw. scheljarensis* (Konoivalova, 1991), and *Leeina callosa* (Rauser, 1940). The latter species first appeared in the upper Tastubian (lower Sakmarian sensu stricto, in the new meaning) and ranges into Sterlitamakian and lower Artinskian (Rauser-Chernousova, 1965; Chuvashov et al., 1990). The same range is possessed by species *Schwagerina scheljarensis* in the Timan-Pechora region (Konovalova, 1991). *Schwagerina whartoni*, *Schw. rowetti*, and *Schw.* aff. *pseudokaragasensis* co-occur with *Eoparafusulina paralinearis* Thorsteinsson, 1960. In the Arctic and Northern Urals, *Eoparafusulina* ranges from Tastubian (sensu lato) to Sterlitamakian (Grozdilova & Lebedeva, 1961; Konovalova, 1991; Nilsson & Davydov, 1997). Evidently, the age of these sequences is upper Tastubian to Sterlitamakian (i.e., Sakmarian *sensu stricto*).

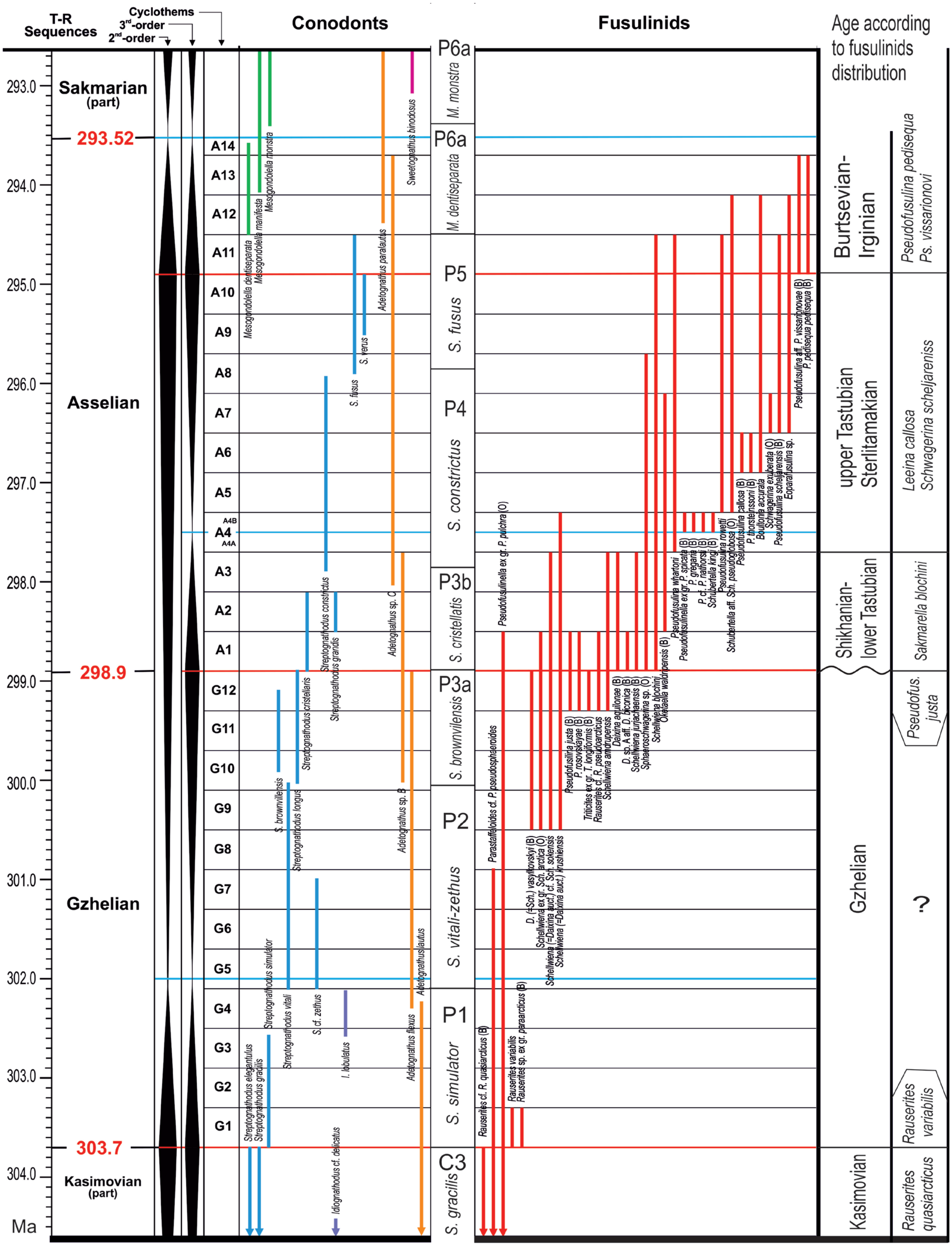

Fig. 1. The relationship between conodont's and fusulinid's age interpretation in the Sverdrup Basin; figure modified from Beauchamp et al., 2022.

The assemblage reported from A11-A13 sequences (Fig. 10 and supplements) comprises *Pseudofusulina* aff. *vissarionovae* Rauser, 1949, and *Ps. pedissequa* Vossarionova 1949. Both species are characteristic of the lower Artinskian in the Urals and Arctic (Rauser-Chernousova, 1949; Rauser-Chernousova and Chuvashov, 1980; Shurinkina et al., 1980; Chuvashov et al., 1990; Davydov, 1997). This assemblage is decidedly older than the one recovered in the type-section from the very top of Belcher Chanel Fm, Grinnell Peninsula, Devon Island (Davydov, 1991), where advanced *Pseudofusulina* and *Parafusulina* are documented.

Summarizing the analysis of fusulinid distribution, we can state that their succession in the Sverdrup Basin is generally the same as in the Urals, Russian Platform, Timan-Pechora, Barents Sea, Spitsbergen, and North Greenland. In the Urals, this succession co-occurs with conodonts and is calibrated with radioisotopic dates (Schmitz and Davydov, 2012). However, the entire succession now correlates to Asselian (*sensu lato*) (Beauchamp et al., 2022). Only a few fusulinids documented in sequence A1 may occur in the Shikhanian Regional stage but also range to lower Tastubian and now correlate with the uppermost Asselian (*sensu lato*). The rest of the fusulinids from sequences A4-A13 are known in the Urals from the upper Tastubian, Sterlitamakian (both are Sakmarian *sensu stricto*), and Artinskian only.

Someone may suggest that these fusulinids originated in the Canadian Arctic during the Asselian and later migrated to Greenland, Spitsbergen, Timan-Pechora, and the Urals in an exact successive order as in the Canadian Arctic but with several million years shift. It is hard to expect, however, that fusulinids migrated from mid-latitudes cool-water environments (Canadian Arctic at 35-45° N) to tropics (Southern Urals 10-15° N) (Golonka, 2011; Scotese, 2021). It is a generally accepted fact that migration always occurs in the opposite direction from the tropics to high latitudes, consistent with the latitudinal diversity gradient (Pianka, 1966; Zhang et al., 2022). Unfortunately, the fusulinids from Raanes and Great Bear Cap formations (Beauchamp and Henderson, 1994) have never been studied, although their preservation is quite good and often, they are abundant (Bensing, 2007). For an unknown reason, this photozoan facies with fusulinids and colonial corals has not been shown in the Sakmarian-Artinskian sequences (Beauchamp et al., 2022).

We have a crisis in the late Paleozoic biostratigraphy, but only at the specific time-slice (Asselian-Artinskian) (Henderson, 2018). The Pennsylvanian fusulinids and conodonts in the Urals and entire Arctic, including Sverdrup region, demonstrate great consistency. However, in the Cisuralian, the age assignment discrepancy between fusulinids and conodonts is as large as 5-6 Myrs. The situation appeared once the Bolivia data were involved in the practice, but these data were not published. So, now we have two independent successions in conodonts and fusulinids with huge age differences (Fig. 1). This situation can be resolved with independent methods (geochemistry, radioisotopic dates). Also, there is a chance to improve our knowledge in the conodont-fusulinid relationship if the fusulinids from the Raanes, Great Bear Cap and the entire Belcher Channel formations are studied as well. The model of two Sweetognathus ex gr. merreli-whitei and morphotypes of different age contradict with fusulinid data (Wardlaw and Davydov, 2000) and does not support by the conodont data from several sections in the North America (Wardlaw and Davydov, 2000; Boardman II et al., 2009; Ritter and Robinson, 2009; Lucas et al., 2017; Kohn et al., 2019).

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New insights on the Artinskian Warming Event (AWE)

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The Palaeozoic was interested by one of the most important glaciations in the history of Earth, the Late Palaeozoic Ice Age (LPIA). The end of this glaciation was characterised by a transition from icehouse to greenhouse climate. This transition started by the Late Pennsylvanian, continued in the Cisuralian and culminated with a sudden change of climatic conditions called Artinskian Warming Event (AWE) (Marchetti et al., 2022). During the Artinskian, a major increase of pCO_2 and Na_2O values in Euramerican successions (e.g., Körner et al., 2003; Montañez et al., 2007; Richey et al., 2020), possibly related to the eruption of the Tarim Large Igneous Province of NW China and Panjal Traps of NW India (Yu et al., 2011; Shellnutt et al., 2011; Zhang et al., 2012; Wei et al., 2014) caused a substantial increase of temperature and aridity that in turn caused the final melting of the Gondwanan ice sheets and a substantial low-latitude continental biota turnover. In fact, tetrapod faunas, ichnofaunas, floras and microfloras from Europe, North Africa and North America are consistent with a dramatic increase in both diversity and relative abundance of drought-tolerant forms during the Artinskian, at about 287 Ma (Marchetti et al., 2022).

Recent research provides new insights on this key event in the climatic and evolutionary history of the Palaeozoic. Griffis et al. (2023) identified a transition from fluvial to mixed fluvial/aeolian deposition starting in the Petrolia Formation of Texas, time-equivalent with the climatic shift related to the AWE. Wei et

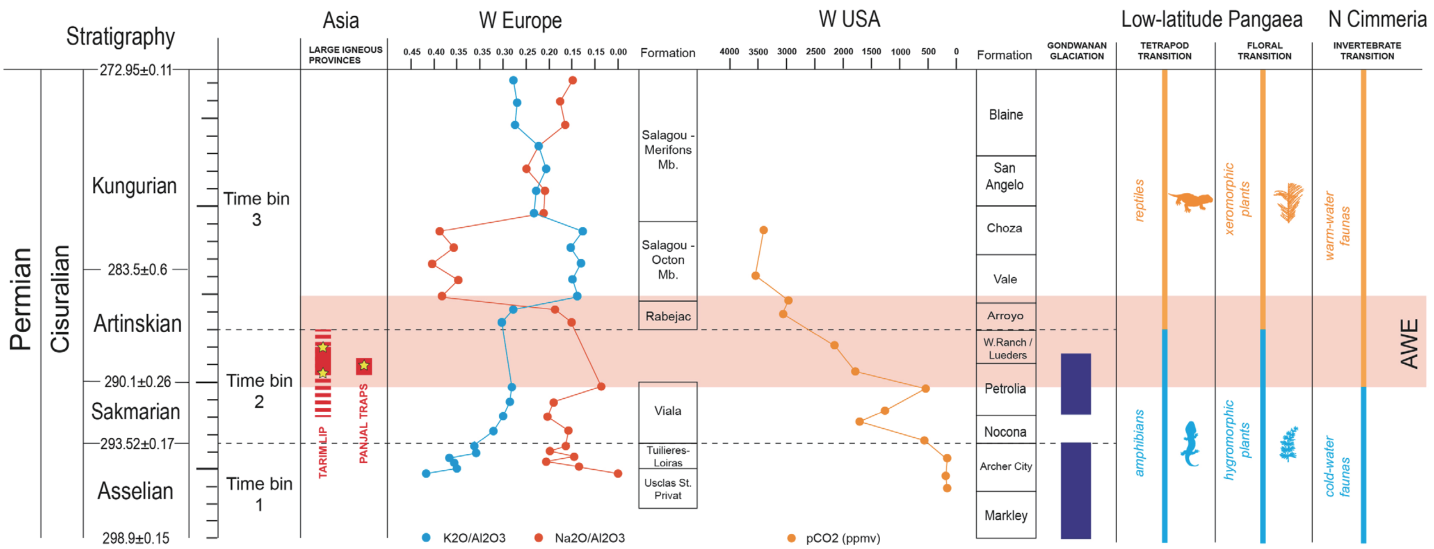

Fig. 1. Cisuralian palaeobiota and climate change. Curves extrapolated from Körner et al. (2003) for western Europe and Montañez et al. (2007) for western USA. Stars represent radiometric dates (see references in the text). AWE=Artinskian Warming Event.

al. (2023), after a cyclostratigraphic analysis on the succession of the Permian Basin (New Mexico and Texas), suggest a possible role of eccentricity in the Artinskian global warming. New findings of plant remains and tetrapod footprints in New Mexico are generally consistent with the AWE (Di Michele et al., 2023; Lucas et al., 2023).

In Europe, most of recent palaeobotanical studies are from the Kungurian units of the Athesian District of Italy. Forte et al. (2023a) revised the Sinigo locality flora (Monte Luco Formation) and evidenced a dominance of xerophytic taxa and the occurrence of xeromorphic characters that support the presence of arid conditions during the middle-late Kungurian. Trümper et al. (2023) described conifer stems *in situ* on a crevasse splay in proximity of a lake system, proving the occurrence of conifers well within the basin. Forte et al. (2023b), in the frame of a review of floras and microfloras from the Cisuralian of the Southern Alps of Italy, reported new sporomorph associations from the Sinigo locality (Monte Luco Formation), the Ulms locality (Verano Formation) and the Nopp locality (Guncina Formation), consistent with the other drought-adapted palynomorph associations from the Athesian District. Vallé et al. (2023) described new sporomorphs from the Grissiano and Gorl localities (Guncina Formation), consistent with semiarid to arid climate conditions. Forte et al. (2023c) evidenced a negative $\delta^{13}C$ shift in the Tregiovo Formation, consistent with the global warming trend. A new plant genus from the same unit shows xeromorphic features (Forte and Kustatscher, 2023). New findings of tetrapod footprints from Europe are generally consistent with the trend observed in the frame of the AWE, both as regards the *Dromopus* biochron (Calábková et al., 2022, 2023a, 2023b; Moreau et al., 2022; Moreau and Gand, 2023) and the *Erpetopus* biochron (Matamales-Andreu et al., 2022; De Jaime Soguero et al., 2023). The occurrence of a strongly seasonal climate at low-latitudes during the Sakmarian was hypothesised by Pint et al. (2023) through sedimentological studies at the Bromacker locality, Germany. This is in general agreement with the overall trend of Late Pennsylvanian-Cisuralian aridification, and it coincides with a smaller biota replacement that occurred before the AWE (Marchetti et al., 2022).

New research from China and surrounding areas evidences the potential impact of the AWE in marine successions. Shen et al. (2023) discussed this in a review of the northern Cimmerian microcontinent marine stratigraphy, palaeobiogeography and invertebrate faunas, in particular as regards the Qinghai-Tibetan Plateau and its surrounding areas. The higher occurrence of warm-water faunas and development of carbonate rocks in the in the South Qiangtang, Baoshan, Sibuma, Karakorum and Southeast Pamir blocks during the Artinskian was interpreted as a consequence of the combination of the AWE and the northward drift of the northern Cimmerian microcontinent. Shen et al. (2023) suggested more possible volcanic CO_2 sources from the Cimmerian microcontinent for the increase of CO_2 that triggered the AWE, in particular the Woniusi basalt (dated between 301 ± 2 and 282 ± 3; Liao et al. 2015) and the Southern Qiangtang volcanics (dated between 300 ± 2 and 279 ± 2; Zhai et al., 2013; Wang et al., 2014). The Zaduo lava sequences may have impacted the climate during the Kungurian, as they are dated between 283.1 ± 1.3 and 276.3 ± 2.2 (Zhang and Torsvik 2022). Wang et al. (2023) provided new U-Pb zircon dating, high resolution chemostratigraphy, and kerogen maceral data from the Liujiang Coalfield, North China. These new data suggest that carbon cycle perturbation, wildfire, and continental weathering in the region were intricately linked with the large-scale volcanism associated with the Tarim-II, Panjal and Choiyoi volcanic provinces. Hou et al. (2023) identified a large sea-level rise in the Liangshan and Chihsia Formations (South China Block) and hypothesised it to be the result of the AWE climate change. Liu et al. (2022) evidenced how the Liangshan Formation is characterised by increased siliciclastic sediments in its upper part, therefore potentially suggesting a dry-humid transition in an overall global warming trend. Sun et al. (2022) investigated the Artinskian Lucaogou Formation in Northwestern China, which was a large perennial lake, the Junngar. The intensification of microbial CH_4 cycling coincided with increasing global temperature probably related to the AWE, and acted as a positive feedback to global warming.

From this recent research, it is clear how new fossil findings as well as different kinds of analyses further support the AWE and provide new possible explanations for it, in both the continental and, for the first time, the marine records (Fig. 1). Future studies should further investigate possible causes, development, magnitude, extent and effects of the AWE on both the continental and the marine records globally and at all latitudes, especially in consideration of its possible similarities with the present-day global warming.

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Excavating the ichnofossils of the Middle to Upper Permian Hornburg Formation (central Germany)

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The abandoned quarry "Held" in Wolferode (municipality Eisleben, Saxony-Anhalt, central Germany) exposes several meters of sedimentary rock from the younger cycle (upper/second cycle) of the Middle to Upper Permian Hornburg Formation. Those fine laminated, fossiliferous clay- and siltstones alternate with internally cross-bedded sandstone beds and are part of the so-called "Blätterton Mb" (Hoyningen-Huene 1960, Falk et al. 1979, 2017). The quarry site has been known for decades as a "trace fossil heaven" by private collectors, but only recently became of interest for more detailed scientific study. This is due to the uncertainties in the stratigraphic position / biostratigraphy of the Hornburg Formation and the potential of stratigraphic correlation of its strata with European, North American and North African terrestrial basin profiles (see articles in *Permophiles* #72, #75 for details).

Trace fossils in the quarry Held profile include microbial induced structures, abundant jellyfish imprints, a rich arthropod track and body imprint fauna, and several tetrapod traces (including swimming traces and trackways). Sediment structures

Fig. 1. Excavation volunteers of 2023 and leaders after a long day in the quarry site (left) and at a field meeting (right).

include ripple cross bedding, load casts, residual horizons, crystal marks (rectangular-shaped and star-shaped crystal marks) and desiccation cracks. These fossils and sedimentary features are not only useful for international stratigraphy but also for the reconstruction of a playa-lake palaeoenvironment (Lucas 2018, Schneider et al. 2020).

More than 30 voluntary scientists took part in the excavations in September 2022 and 2023, which will continue in 2024. The project is conducted by the Museum of Natural History Magdeburg, the Technical University Bergakademie Freiberg, the Geological Survey of Saxony-Anhalt (all Germany) and the University College Cork (Ireland). The international excavation team included students, PhDs, post-docs and professors from Colombia, Germany, Ireland, Italy, Slovakia, and the UK.

In 2022, the first third of the about eight meters thick strata were checked for the sedimentary patterns and fossil content in a millimetre-scale. The originally 25 m^2 of excavation surface in 2022 was doubled in 2023. In addition, the profile from 2022 was extended by another three meters in depth, reaching more continuous bedding surfaces, and more importantly, better-preserved tetrapod imprints and trackways. Ichnofossil associations (tetrapod trackways and arthropod trackways, sometimes crossing each other) were also more common as fossil-bearing slabs became bigger. Most of the findings are currently prepared for scientific investigation, which is pending. Preliminary analysis revealed at least two distinctive tetrapod imprint morphologies, that are likely to be associated with *Dromopus didactylus* (probably diapsid trackmaker) and *Capitosauroides* (probably therapsid trackmaker). The latter is known from the “Konberg Quarry” site (also upper cycle of the Hornburg Formation, but slightly older than this excavation profile), a few kilometres from the quarry “Held” excavation site (Buchwitz et al. 2019, 2020). In the Hornburg Formation, Capitosauroides-like specimens have formerly been reported as *Amphisauropus*, which are stratigraphically associated with Lower to Middle Permian sediments as opposed to a Late Permian age for *Capitosauroides*. The validation of *Capitosauroides*-like material in the quarry “Held” site is therefore of highest importance to validate a Late Permian age of the Blätterton Mb.

The excavations combine traditional methods, like profile documentations and logs, with modern techniques. In the 2023 season, photogrammetry was successfully applied for the first time to map the excavation process of the whole outcrop. Depth maps of individual surfaces will be an invaluable tool for future determinations of arthropod and tetrapod traces, including the *Capitosauroides*-like specimens.

As outlined, the excavations in the Upper Hornburg Formation in 2022 and 2023 were a great success. Many research questions, especially on tetrapod and arthropod tracks, are waiting to be solved in the next years.

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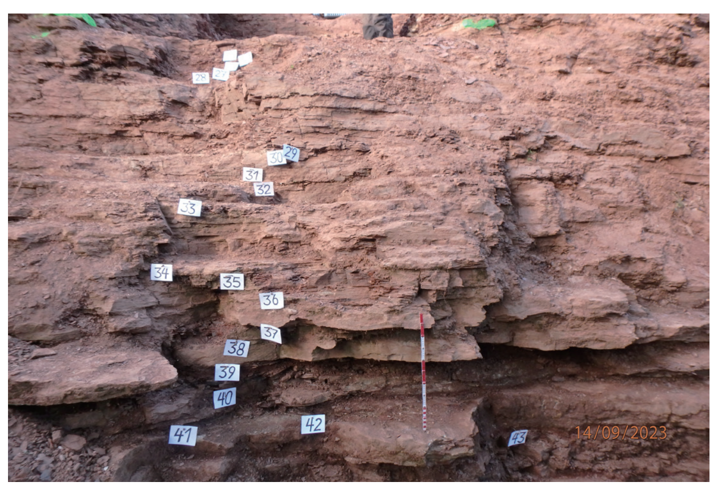

Fig. 2. The millimetre-scaled profile documentation included lithology, sedimentary patterns and fossil content of every unit/bedding plane (43 units in total).

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Protracted destabilization and collapse of peat mire ecosystems at the Permian-Triassic boundary recorded by a sequence of related transtensive sub-basins in central and southern Mongolia

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Extensive field work in central and southern Mongolia over the past few years has shown that during the Late Permian inertia-driven transtensive reactivation of primordial fracture zones gave rise to the development of a sequence of related yet disconnected fault-bounded sub-basins; some of these became the locus of substantial peat accumulation that evolved into economically important coal deposits. The vast majority of these sub-basins sporadically outcrop north of the Chinese border from c. 91°-109°E with the main concentration in the South Gobi "Basin". Global wrench tectonics, a new global tectonic theory based on inertia principle for the rotating Earth, in conjunction with the ubiquitous orthogonal fracture/fault system best explains the sub-basins scattered spatial distribution associated with wrench faults. Syn-tectonic sedimentation continued across the Permian-Triassic boundary (PTB) within the majority of the studied sub-basins, recording a distinct climatic change from humid cold-temperate coal-forming environments, to relatively arid desolate conditions in the Early Triassic characterized by common carbonate nodules, barren greenish mudstone and alluvial fan deposits. Fossil wood growth rings shows a decrease in size towards the PTB possibly indicating deteriorating growing conditions. The final collapse of the long-lived peat mire ecosystem was protracted, with a transitional zone extending for an estimated c. 330-530 ky based on interpreted 100 ky Milankovitch cyclicity. The studied sub-basins in central and southern Mongolia are located proximal to two controversial suture zones. However, the zones do not show major thrusting and regional metamorphism, and given the complete absence or only minor thin tuffs within the studied Permo-Triassic successions it could be argued that the sutures are not only cryptic but non-existent.

Central Mongolia

The ongoing work in central Mongolia has mainly concentrated on a c. 26 km long, NE trending, V shaped transtensive fault-bounded sub-basin in the Bayanjargalant area c. 135 km SE of Ulan Bator. The c. 2,600 m thick sedimentary fill is probably the most significant Permian-Triassic succession in Mongolia. The fill was warped into a relatively gently dipping asymmetrical syncline as a result of wrench tectonic transpression (cf. Storetvedt, 2003), with sporadic outcrops over a maximum width of c. 12 km. The sub-basin developed along the southern margin of the Permian Mongol-Transbaikalian Seaway, formerly known as the Khangai-Khentei Geosyncline.

The Permian Mongol-Transbaikalian Seaway is widely regarded as the southern extension of the Permian Mongol-Transbaikalian biogeographical province of the Boreal zoogeographical realm (see Manankov, 2012, for a review). The Permian succession is sporadically exposed over a length of c. 900 km and a maximum width of c. 150 km, with the most extensive outcrops west of Delgertsogt in the western sector. The Permian Mongol-Transbaikalian Seaway had its opening to the northeast, towards the polar region of the time (cf. Biakov et al., 2013), and thus may reinforce the possibility of a relatively cool Late Permian climate in northeastern Mongolia. Minor exposures of lower Tatarian limestone beds proximal to Binder (c. 48° 35' N / 110° 33' E) clearly argue for periods with warmer climate during that time.

The Permian Mongol-Transbaikalian Seaway experienced several deep regressive events during the Permian as indicated by the work of Manankov (2012) as well as data collected during recent field work around Adaatsag, Delgertsogt, Tsenhermandal, Jargalthan, Bayan, Bayantsagaan, Bayanjargalant, Binder and other localities. Results from this study show that at the end of the Permian the relatively shallow epicontinental seaway underwent a dramatic drainage event (Michaelsen et al., 2000, Huang et al., 2011, Burges et al., 2014). This major prolonged degassing event, which included a range of toxic gasses, led to the most dramatic biological disaster in Earth history (cf. Michaelsen, 2002).

Outcrops along the seaway are characterized by a high sandstone/mudstone ratio, strongly dominated by relatively well sorted fine-medium grained planar sandstone beds characterized by dense orthogonal joints which were probably inherited from older basement rocks during wrench (shear) deformation (Michaelsen and Storetvedt (in press) and thus having an adverse effect on outcrops. Sandstone framework grains are predominantly made up of angular to sub-angular quartz and lithics showing low to moderate sphericity (Fig. 1C), indicating limited transport from transitional continental source to sink. Boreal-type brachiopods, bivalves and bryozoans appear to be relatively rare and concentrated in certain horizons (i.e. including shell beds). A relatively low energy environment with a tidal influence is indicated by the often-well-preserved nature of the brachiopod and molluscan fossils.

Regional mapping work in 1947 included the Bayanjargalant study area, and it established a Late Permian age based on analysis of marine fossils in the middle part of the c. 2,600 m thick sedimentary package. Subsequently the Permian age was reconfirmed by another Russian mapping expedition in 1965 based on plant fossils in the lower-middle part of the succession. The significant sedimentary fill is sub-divided into five informal stratigraphic units which are briefly described in the following (in descending stratigraphic order):

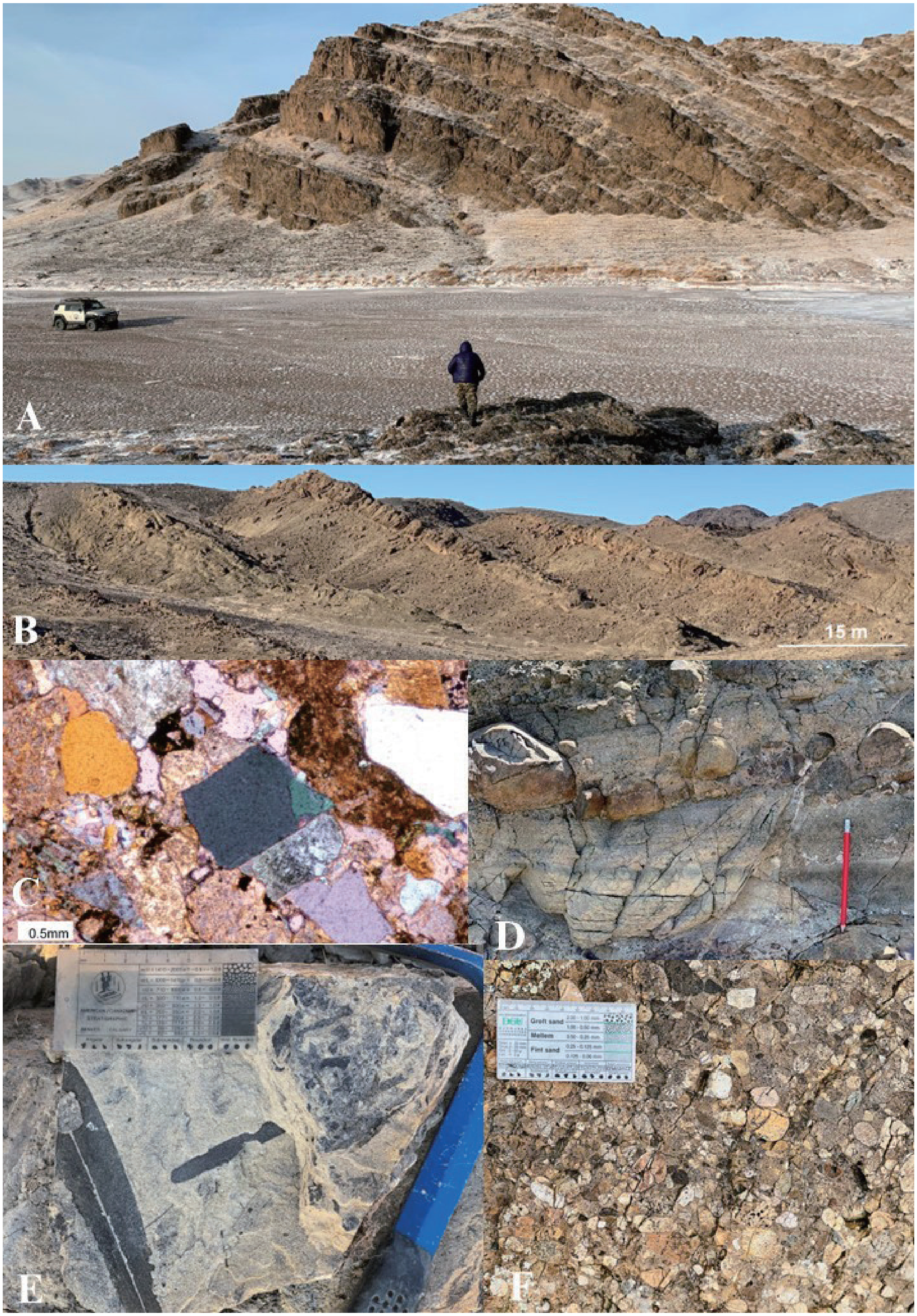
The Lower Triassic barren upper unit (T_1) is estimated to be c. 960 m thick. The topmost c. 240 m part of the unit is the best exposed and dominated by sandstone and polymictic conglomerate with subordinate greenish siltstone. This unit contains a massive 40 m thick alluvial fan deposit in the northern part, characterized by clast-supported conglomerate (Fig. 1F). The bedding dips are gentle (Fig. 2). No organic material was observed during field work or reported from this unit. The 720 m thick lower part of the Lower Triassic unit is predominantly fine-grained and as such poorly exposed, composed of greenish siltstone, mudstone, sandstone and minor conglomerate. These deposits are similar to early Triassic deposits in the South Gobi Basin (see below).

The topmost Upper Permian transitional unit (P_{2cn4}) is c. 180 m thick and dominated by shallow marine dark grey siltstone, carbonaceous mudstone, coaly wisps, a thin calcareous mudstone bed and subordinate sandstone and conglomerate. Some sections of this unit are highly bioturbated by an assemblage of *Thalassinoides*, *Skolithos* and *Planolites* ichnofossils. Numerous shell fragments were recently discovered within siderite nodules.

The middle stratigraphic unit (P_{2cn3}) is characterized by c. 420 m thick coal-bearing strata. It is made up of a marine shell bed at the base, polymictic conglomerate, sandstone, siltstone, carbonaceous mudstone and eight high ash coal seams (Michaelsen, 2016). The rapid thickness variations and unstable nature of the seams strongly suggest a syn-tectonic influence on their development, common within Upper Permian coal measures in Mongolia as well as the Rangal Coal Measures, North Bowen Basin, Australia (cf. Michaelsen et al., 2000). Oviposition lesions (DT228 in particular) from arthropod-plant interaction were observed on leaves from this unit in the recently mapped far southern area. The peat mire ecosystem is considered to have developed during boreal to temperate climatic conditions along the shores of the Permian Mongol-Transbaikalian Seaway. The seaway was likely frozen during the dark cold winter months, and benefited from moist air currents along the seaway during the relatively short summer months, with the short nights favoring steady plant growth. This is in agreement with recent work by Cai et al. (2022) in the Tsagaan Tolgoi sub-basin c. 530 km to the southwest in southern Mongolia, where detailed growth ring analysis suggested relatively short growing seasons. Moreover, Cai et al. (2022) discovered a growth interruption with inflated cells was present in the secondary xylem, indicating that the tree had survived climatic damage, probably an early spring cooling event. Interestingly, x-ray diffraction analysis results from a 3t bulk sample from the basal coal seam shows that the ash is strongly dominated by SiO_2 (77%). It is noted that the very high SiO_2 content is similar to the thick basal seam in the Late Permian Tsagaan Tolgoi sub-basin. In the basal seam 0 the SiO_2 content averages 71%, decreasing upwards to 51% in the topmost 8th seam.

The P_{2cn2} unit is c. 360 m thick and dominated by well-sorted fine to medium-grained shallow marine sandstone beds, subordinate mudstone, siltstone and conglomerate. Sporadic and very fragmented outcrops of sandstone strike ridges reveal rich organic material in places indicating marked base-level changes during emplacement of this unit. Oviposition lesions (DT246 in particular) were recently observed on a branch of a seed plant from this stratigraphic unit. It is noted that the oviposition lesions are almost twice the size of previous DT246 on Taeniopteris foliage at the Colwell Creek Pond locality in north-central Texas, of latest Early Permian age (Schachat et al., 2014). Further, a sample from one outcrop reveals a fertile spike of a taeniopterid, the morphology did not develop until earliest Late Permian and continued into the Triassic (Rigby, pers. com.).

The P_{2cn1} basal unit is c. 700 m thick and dominated by shallow marine sandstone beds with subordinate siltstone and conglomerate. Rare angular outsized clasts (up to 1.8 cm in length) observed in very well-sorted laminated siltstone in this unit was considered by Michaelsen (2016) to represent glacial derived drop stones. Petrological analysis of sandstone samples showed common elongate monocrystalline quartz slivers, indicating a volcanic source. Organic material is common in some beds indicating significant base-level changes during deposition of this unit (cf., Hallam and Wignall, 1999). Rufloria theodori fossils were documented from this basal unit by a Russian mapping expedition in 1965 and by Erhembaatar et al. (1993).



Fig, 1. A. Upper Permian fluvial deposits exposed within the Bulag Suuj sub-basin; B. Well developed Lower Triassic ?100 ky Milankovitch cyclothems, Tsagaan Tolgoi sub-basin; C. Photomicrographic example from Permian Mongol-Transbaikalian Seaway sandstone showing textural immaturity; D. Active fill of Lower Triassic mobile braided river channel at Bayan Ovoo East sub-basin; E. Upper Permian (Changhsingian) leaf imprints of Sulcivius and Cordiates above topmost seam, Tsagaan Tolgoi sub-basin; F. Massive 40 m thick Lower Triassic alluvial fan deposit, Bayanjargalant sub-basin.

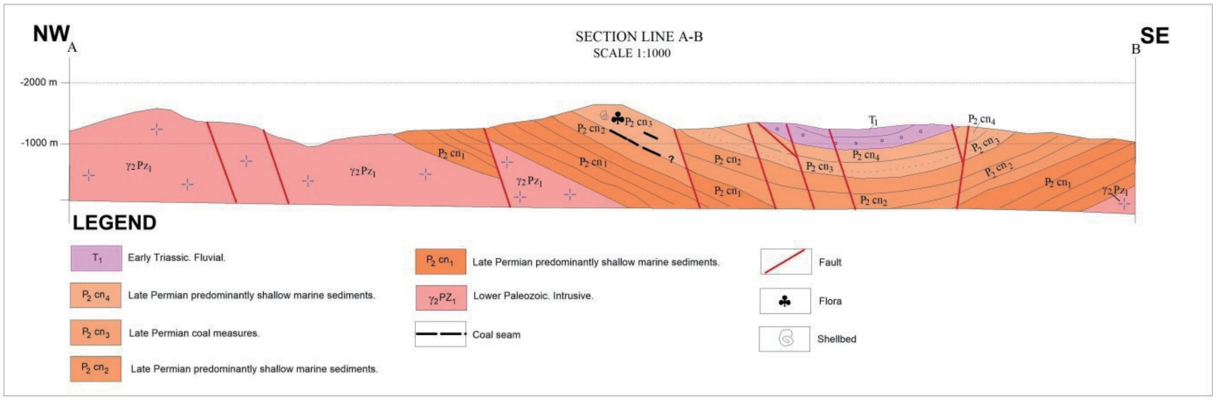


Fig. 2. Schematic NW-SE cross-section of the Permian-Triassic syncline at Bayanjargalant, central Mongolia.

While the original P_{2cn} stratigraphic nomenclature by Erhembaatar et al. (1993) has been maintained (for now), units P_{2cn2-4} are considered here to be Upper Permian whereas the lower P_{2cn1} unit might be Middle Permian. Given the significant thickness of the predominantly shallow marine succession, coupled with the slow sedimentation rates indicated by the work of Manankov et al. 2006 (see their fig. 2), it must represent a very substantial time span.

In summary, the significant 2,600 m thick sedimentary package shows that the shallow epicontinental seaway underwent several marked regressive events followed by dramatic draining at the end of the Permian. The sedimentary infill records a protracted transition from humid cold-temperate climate during Late Permian times to relatively arid terrestrial conditions during the early Triassic. Significantly, the study area is situated proximal to an assumed suture zone – a tectonic element that represents the minimal and complex surface remains of a fingered Mongol-Okhotsk Ocean. However, the tectonic belt does not show the presumed shortening, major thrusting, or regional metamorphism, and the complete absence of tuffs within the thick sedimentary package is again inconsistent with plate tectonic expectations.

Southern Mongolia

The ongoing research on Permian-Triassic sub-basins in southern Mongolia builds on substantial work since 2004 on >50 exploration and mining licenses from 94° -108° E as well as two large oil and gas blocks, with the vast majority situated within the South Gobi "Basin" (i.e., a concentration of predominantly Late Permian transtensive sub-basins). The work included, but was not limited to, field mapping, logging and sampling of drill core and sections, review of downhole logs and 100's of km of seismic profiles, paleocurrent and in-situ stress measurements and inspection of all coal mines.

The South Gobi Basin is well known for its vast energy resources, which includes the world class coal deposit at Tavan Tolgoi with potential coal resources of 10 Gt (i.e., to a depth up to 1,200 m). The NE trending V-shaped transtensive sub-basin is fault-bounded and extends over a maximum strike length and width of c. 26 x 12 km. The coal-bearing sequence includes 16 seams, with individual seams ranging in (measured net) thickness from < 1 to almost 100 m, with the quality and thickness changing rapidly. The Roadian-Wordian age of the Tavan Tolgoi coal measures is well established from macroflora which is identical to the central part of the Angara floral realm. The Tavan Tolgoi flora includes swamp or lake margin plants and ferns such as *Callipteris confluens*, *Pecopteris* and *Sphenopteris*. Strap-shaped *Rufloria* leave imprints and *Cordaites gracilentus* gymnosperms were also reported. Interestingly, Glossopteris leaves (Rigby, 1978) were reported by Naugolnykh and Uranbileg (2018) from Roadian-early Wordian deposits in southern Mongolia, i.e., outside the Glosspterids boundary in the Southern Hemisphere (cf. McLoughlin and Slater, 2021), and thus further challenging the integrity of plate tectonics (Pratt, 2000, Storetvedt, 2003, James, 2018).

Although the coal measures within the economically important Tavan Tolgoi sub-basin are of Roadian-Wordian age, the vast majority of the transtensive coal-bearing sub-basins in southern and central Mongolia are considered here to be related to the Late Permian (Fig. 3), with syn-tectonic deposition extending across the Permian-Triassic boundary. The Permian-Triassic boundary was well documented by Johnson et al. (2008) within the coal-bearing Tsagaan Tolgoi sub-basin, located c. 90 km south of Tavan Tolgoi. The entire sub-basin was recently mapped and documented by the authors during many weeks of field work which included target generation and deep stratigraphic drilling in the western sector. The coal-bearing deposits occur within a c. 21 km long and up to 3.6 km wide fault-bounded sub-basin. The Permian-Triassic sub-basinal fill was estimated by Orolmaa et al. (1999) to be c. 1,500 m thick with Upper Permian coal-bearing Yamaan-Us Formation at the base, estimated here to have a true thickness of c. 570 m. Identical to the Bayanjargalan coal meaures, a total of eight coal horizons are preserved, with one-two main seam(s) developed near the base. Three coal-bearing zones are divided by two c. 93-241m thick clastic packages characterized by shallow marine sedimentary structures such as disturbed bedding and hints of hummocky cross stratification (cf. Surlyk and Noe-Nygaard, 1986). A similar configuration was observed within the Zag Zuuj and Soumber coal-bearing sub-basins in the western sector of the South Gobi Basin with two thick clastic units dividing three coal zones. *Cordaites sulcivius* leaf imprints (Fig 1E) are by far the most dominant within the coal measures (i.e., similar to the coal measures at Bayanjargalant

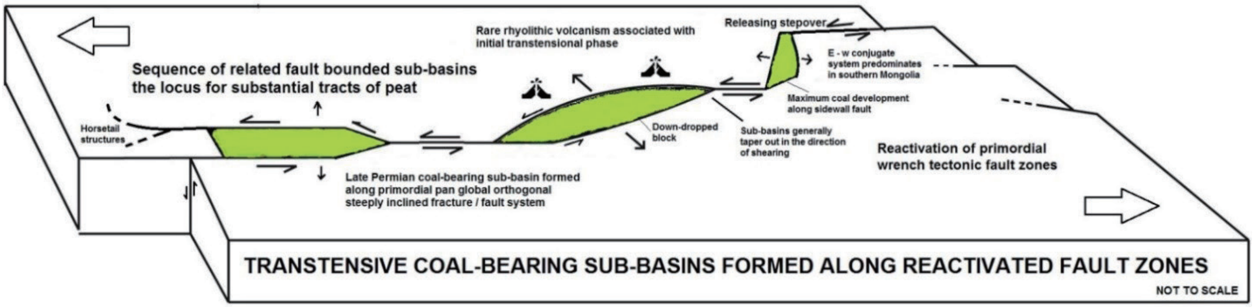


Fig. 3. Schematic illustration of the sequence of related transtensive Permian-Triassic coal-bearing sub-basins formed along reactivated primordial fault zones in central and southern Mongolia. Not to scale.

530 km to the NE), with minor *Lepidophyte* and *Cicadocea* (*Guramsania hosbayari*) reported by Orolmaa et al. (1999). A clear marine influence on peat mire deposition is evident by the sulphur content of the eight coal seams, sedimentary structures and the recent discovery of a 1 cm trilobite fragment at the base of the coal measures.

Rudimentary analysis of well-developed growth rings during recent field work indicates a marked decrease in thickness upwards towards the Permian-Triassic boundary, considered here to mirror deteriorating growth conditions. More detailed growth ring analysis by Cai et al. (2022) suggested relatively short growing seasons, with the discovery of growth interruption, probably recording an early spring cooling event in a temperate climate.

The work by Johnson et al. (2008) shows that the Permian-Triassic boundary within the Tsagaan Tolgoi sub-basin is transitional over c. 50 m, with more recent logging of another section by the authors indicating c. 80 m. The siltstone dominated transitional zone, which conformably overlays the eighth topmost Upper Permian coal seam (i.e., seam 7 with the basal seam termed seam 0), is characterized by a change of mudstone color from grey to light green, decimeter-sized carbonate nodules appear, and petrified wood fragments and siderite horizons gradually disappear. While petrified wood gradually decreases within the transitional zone a 9.5 m long and 35 cm wide fossil tree trunk was recently observed in-situ in the upper part of the transitional zone by the authors. While the transitional zone is relatively thick at c. 50-80 m, the spore-pollen data presented by Johnson et al. (2008) record a more abrupt change in the middle part of the zone.

The results from the well-studied Permian-Triassic sections at Tsgaan Tolgoi has been applied to identify Upper Permian – Lower Triassic stratigraphy in other studied sub-basins in central and southern Mongolia such as Bayanjargalant, Khuts Uul, Tsant Uul, Navtgar Uul, Erdenebulag, Bayan Ovoo west, Bulag Suuj (Fig. 1A), Yangir and other sub-basin in the east and Zag Suuj, Soumber and Noyon in the western part of the South Gobi Basin. The results from this detailed and extensive field work show that vast tracts of previously mapped Upper Permian sediments are in fact Lower Triassic.

Early Triassic fining-upward cycles with an average thickness of c. 15 m are well developed above the transitional Permian-Triassic boundary zone at Tsagaan Tolgoi (Fig. 1B). Importantly, these fining-upward cycles are also recognized in sub-surface data in other sub-basins in the eastern sector of the South Gobi Basin (i.e., with identical thickness). These well-developed cyclothems are considered here to represent orbital climatic forcing (i.e., 100ky Milankovitch climatic cycles). Presuming sedimentation rates of c. 15 m / 100 ky and 150 m / 1 My, the mass extinction interval (MEI) might thus represent a prolonged period of c. 330-530ky. This is significantly longer than the 60 ky estimated from condensed marine MEI sections by Burgess et al. (2014) and shorter than the 700ky proposed by Huang et al., 2011 based on sedimentary records of astronomical tuning. The protracted destabilization and collapse of the Mongolian peat mire ecosystems at the Permian-Triassic boundary might be due to the relative proximity to the Siberian Traps, the largest continental flood basalt province, which extended as far south as the Irkutsk region.

Significantly the south Mongolian Permian-Triassic sub-basins are located proximal north of the controversial Suolionkheer Suture Zone. In the absence of the expected subduction related features, including significant regional metamorphism and large-scale thrusting, plus the absence or very limited occurrence of tuff beds in the studied sub-basins, it could be argued that subduction has not taken place.

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Report on the Conference "Across the End Permian Great Extinction: From Field Studies to Scientific Results" held, from August 29 to September 2, 2023, at the University of Lausanne, Switzerland

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The "Across the End Permian Great Extinction" Conference took place from August 29th to September 2nd, 2023 at the Synathlon Building on the campus of the University of Lausanne, Switzerland (Fig. 1).

Nearly 50 scientists attended the Conference, and 40 presentations were given during three days (Fig. 2).

During the opening introductory remarks, we celebrated and paid tribute to Dr. Aymon Baud's fifty years of continuous Permian-Triassic field research. A welcome address was given by Professor Niklas Linde, Dean of the Faculty of Geosciences and Environment and by Professor Allison Daley, Director of the Institute of Earth Sciences.

Professor Torsten Vennemann, Professor in the Faculty of Geosciences and Environment, highlighted in his talk the new results from the Permian-Triassic scientific program in Switzerland, quantifying decamillennial changes in carbon cycling, and climatic and biotic responses to Late Permian-Early Triassic volcanism within the research program of a Sinergia collaborative project funded by the Swiss National Science Foundation. Contributor to the Sinergia program, Aymon Baud also looked back over fifty-five years of continuous Permian-Triassic field research and publications in collaboration with the Geological Institute of the University of Lausanne, Switzerland. This was presented on five posters during the conference, the corresponding text will also be published in the Mémoire de Géologie, volume 50, Lausanne. This publication is scheduled to be online from February 2024.

The talks were organized thematically into a plenary session followed by six main sessions:

1-Biotic responses to extreme climatic and environmental crises with three keynote talks, by Sara Pruss, Elke Schneebeli and Amalia Spina, and talks by William Foster, Xiaokang Liu, Charline Ragon, Monica Gomez-Correra, Jood Al Aswad, Sylvie Bourquin and Benoit Beauchamp.

2-Paleogeographic views with a keynote talk by Lillit Sahakian, and further talks by Dimitri Papanikolaou, Karmen Fio-Firi, Christian Vérard, Charles Henderson, Benoit Beauchamp

Fig. 1. The University of Lausanne Synathlon building.

and Sylvain Richoz, and a poster presented by Bilal Wadood.

3-New geochemical tools and modelling with a keynote talk by Jonathan Payne, and talks by Torsten Vennemann, Stella Buchwald, Franziska Blattmann, Moghadam Mahdi Maaleki, Oluwaseun Edward and Thierry Adatte.

4-Biochronology, and new time calibrations of the Permian to Triassic transition with a keynote talk by David Ware and talks by Thomas Brühwiler, Marc Leu, Charles Henderson and Ali Murat Kiliç.

5-Specific facies - Fossil-Lagerstatten and Coquina limestones with a keynote talk by Arnaud Brayard and talks by Aymon Baud and Sakineh Arefifard (by zoom).

6- Introduction to the local Triassic deposits and the fieldtrip by Aymon Baud.

The international team of speakers (2) presented data on Permian and Triassic rocks and fossils from around the world, including key examples located from the Arctic to Gondwana margin, from both mid latitude and low latitude.

After three days of scientific presentations and posters, participants received the excursion guide booklet prepared by Aymon Baud, and then embarked for the day on September 2 to local Triassic outcrops, starting with a presentation by Jean-Luc Epard of the regional geology made in La Corniche on the UNESCO Lavaux site. The excursion continued with an examination of the Anisian limestone at Saint-Triphon, followed by a visit to the Upper Triassic salt mine at Bex, with a look at the growth of local vineyards on Triassic rocks. In Saint-Triphon, participants visited the Fontenaille quarry (lower-middle Anisian) (Fig. 3) and the Andonce quarry (middle Anisian).

In the Bex salt mine, participants saw anhydrite and gypsum rocks of Norian age. The links between landscape and underlying geology were also highlighted by comparing vineyard growth on gypsum and on limestone.

The day ended with the tasting of a local dish, cheese-raclette, on the terrace restaurant of an alpine chalet in Prafandaz above the village of Leysin, a unique location with a view of the Rhône flowing into Lake Leman and the whole Jura chain rising beyond the hillsides.

Lausanne Organizing Committee, Earth Science Institute

Profs. Allison Daley, Michel Jaboyedoff, Jean-Luc Epard, Torsten Vennemann, Thierry Adatte; coordinator Dr Aymon Baud.

Scientific Committee

Profs Benoit Beauchamp (University of Calgary), Hugo Bucher (University of Zurich), Charles Henderson (University of Calgary), Nicolas Goudemand (ENS Lyon), Jonathan Payne (Stanford, USA), Sara Pruss (Smith College, Northampton, MA, USA).

Acknowledgements

The organisers of the meeting would like to thank first the SNSF Scientific Exchanges for the financial support of the Conference that allowed six participants from six countries to participate and give talks. We also thank the "Fondation pour l'Université de Lausanne" for their financial support in the organization of this scientific congress, which enabled the conference to take place and allowed us to give financial support to some participants who had no other funding source to attend the meeting.

We would particularly like to thank Catherine Schlegel Rey for her work as editor of the special volume in the Mémoires de Géologie de Lausanne and we are very grateful to numerous people who helped with the smooth running of the conference, including Anne-Marie Chagros, Krystel Fazzi, Pierre Gueriau, Nora Corthésy, Sinéad Lynch, Farid Saleh, Damien Pas, Harriet Drage, Gaëtan Potin, Lorenzo Lustri, and Nadia Santodomingo.

Abstract and short text list are available at: https://www.unil.ch/files/live/sites/iste/files/shared/X.Library/Memoirs%20of%20Geology/Permo-Trias23%20abstracts.pdf

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Fig. 2. Outside group photo of part of the participants-speakers between two sessions.

Fig. 3. Excursion participants examine the overturned lower Anisian limestone of the Fontenaille quarry at Saint-Triphon.

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TWO FUNDED PROJECTS BY SPS

Establishing a high-resolution numerical geological timeline for the Permian

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Due to the complexity of fossil preservation and sampling and the limitations of fossil distribution, the usage of the first occurrence of index fossils to correlate stratigraphic units across the whole world sometimes comes to problems. For example, the index fossils are sometimes contradictory to many physical and chemical markers of isochronous significance. In addition, the definition of the index fossils mostly adopts a marine section as the standard, which makes it difficult to solve the problem of terrestrial stratigraphic correlations. Therefore, in recent years, the method of defining GSSPs by the "first appearance" of fossils has been questioned and challenged continuously (Aubry et al., 1999; Lucas, 2018; Davydov, 2020). These problems are significant in the Permian as well. For example, the hiatus during the end-Guadalupian has caused difficulty in marine and terrestrial global correlations (Shen et al. 2020). Therefore, some attempt to construct a high-resolution multidisciplinary temporal framework is needed to help global stratigraphic correlations and better understand the tempo and interrelationships among the geological and biotic events.

This project aims to integrate terrestrial and marine Permian stratigraphic data as much as possible and estimate their order to provide more correlation markers with higher temporal resolutions. It is anticipated that this would improve the stratigraphic correlations to some degree or at least provide quantitative evaluations of possible index fossils. The expected result of this project is to provide a high-resolution Permian timeline and an effective method that can be extended to other intervals. In this project, I propose to use quantitative stratigraphic methods to correlate abundant sections from the Permian and build a high-resolution timeline based on the estimated age of all kinds of geological events (e.g. first and last appearances of all terrestrial and marine fossil records, ash beds, geochemical records, etc.). Quantitative stratigraphic methods (e.g. CONOP (Kemple et al., 1989), UAM (Guex and Davaud, 1984), etc.) could integrate as much available data as possible and solve contradictions by mathematical rules. The selected sections processed by UAM could work as a composite section to improve correlations among abundant section data calculated in the CONOP. CONOP would give the results with the fewest misfits by adjusting the range of geological events and using

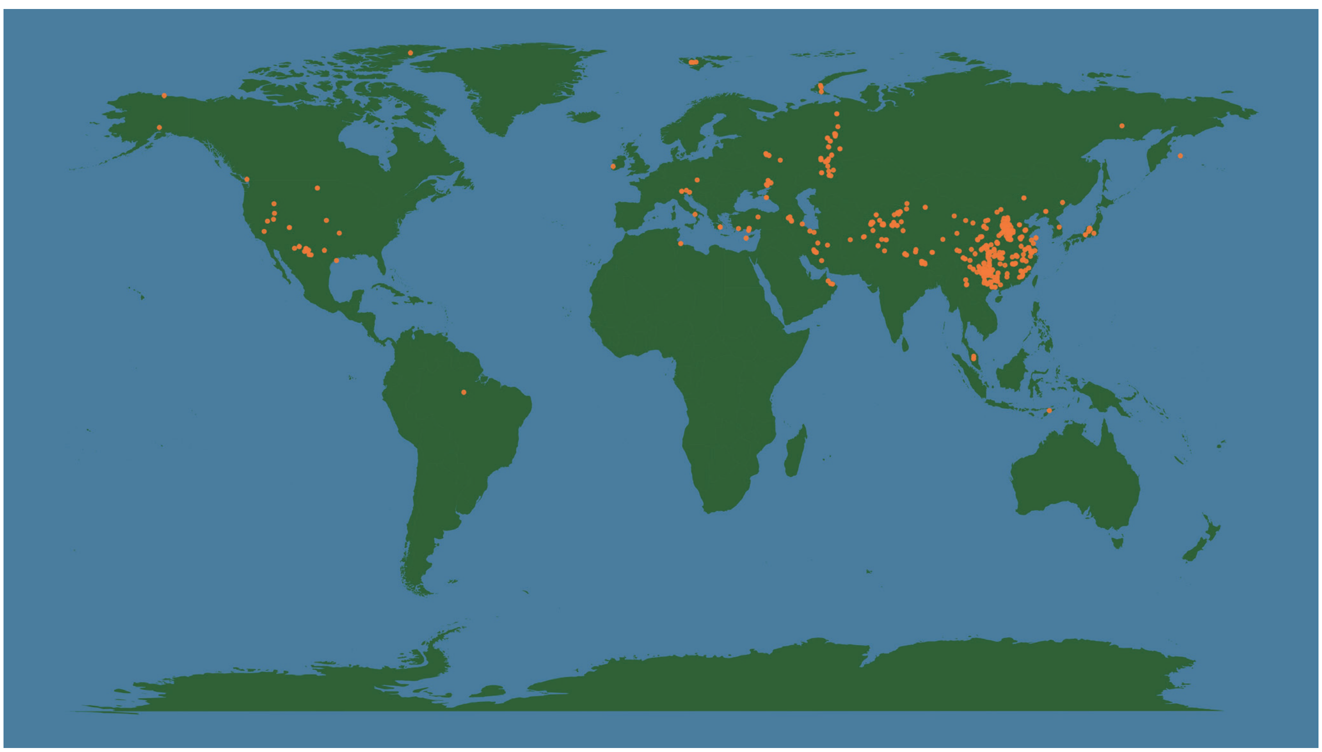

Fig. 1. Current Permian sections with more than 10 species recorded in the OneStratigraphy database.

the simulated annealing algorithm to find the optimal solution. With multiple rounds of calculations, I could statistically estimate the accuracy of every geological event and give their numerical confidence interval. They can then be used to evaluate the importance and effectiveness of index fossils. Therefore, the results could favor the traditional way of choosing and evaluating index fossils as well. The source data (Fig. 1) would come from the database OneStratigraphy (http://onestratigraphy.ddeworld.org/) at Nanjing University and the Geobiodiversity Database (http://www.geobiodiversity.com/) at Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences. OneStratigraphy and the Geobiodiversity Database are platforms specially designed for the sharing and usage of stratigraphic data and they have accumulated stratigraphic data from more than 1500 sections from published references during the Permian.

Ultimately, this project aims to build a high-resolution timeline with the resolution of tens of thousands of years for the Permian by using stratigraphic databases, quantitative stratigraphic methods, and network analysis. It would support stratigraphic correlation and evolutionary studies in this interval.

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Petrographic analyses of the Permian turbiditic rocks of Tuzancoa Formation in the Huayacocotla anticlinorium, east-central Mexico: a new insight on provenance

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Sedimentary petrological analyses provide a highly effective approach to identify the nature, the erosional trace, and the affinity of the source rocks through both space and time. In Mexico, Permian sedimentary successions are sporadically distributed, and occasionally overlie basement rocks which collectively define different tectonostratigraphic terranes and/or blocks with distinct affinities. For instance, in the Huayacocotla Anticlinorium, areas such Molango, Otlamalacatla, Calnali, and Tuzancoa in Hidalgo state (Fig. 1A) are part to a geological structure produced by the Cretaceous-Paleogene Laramide Orogeny; and its eroded core exposes part of the deformed Precambrian-Paleozoic basement of the Sierra Madre Oriental, which in turn is associated to the Oaxaquia block.

In particular, the Paleozoic rocks of Hidalgo have few studies. Pioneering work (e.g., Carrillo-Bravo 1961; 1965) linked these units to the Permian Guacamaya Formation of Ciudad Victoria, Tamaulipas, however, differences in lithology and origin led to distinguishing the Hidalgo units from those in Tamaulipas, allowing that the Permian rocks of Hidalgo were recognized as Tuzancoa and Otlamalacatla formations (Ochoa-Camarillo 1996). Later both formations were consolidated in the Tuzancoa Formation (Rosales-Lagarde et al. 2005). Biostratigraphic studies indicate a Permian age based on Cisuralian fossils such as brachiopods, trilobites, gastropods and bivalves, found in the calcareous debris, and epiclastic rocks. A Late Pennsylvanian age is possible at its oldest part (Pérez-Ramos 1978; Sour-Tovar et al. 2005).

The Tuzancoa Formation is more than 700 m-thick, and overlies Precambrian metamorphic rocks of the Huiznopala Gneiss. A discordance and/or a tectonic contact by lateral fault is inferred (Rosales-Lagarde 2002), and it unconformably underlies the Mesozoic units (Fig. 1B). This formation consists of five lithofacies: (1) volcanic facies: basaltic-andesitic lava flows, (2) siliciclastic turbidites, (3) volcanoclastic turbidites, (4) calcareous detrital flows, and (5) conglomerates (Fig. 1B, C).

Rosales-Lagarde (2002) created a comprehensive geological map, as well as studies of the textural mineralogical, and geochemical composition of Tuzancoa Formation, but these studies were mainly focused on igneous and several volcaniclastic levels. Therefore, the aim of this project is to analyse the turbiditic rock levels (Facies 2 and Facies 3; Fig. 1B) and to obtain detailed petrological information that will allow us to define the provenance of these clastic deposits. According to geological maps and stratigraphy by Rosales-Lagarde et al. (2005; Fig. 1B), the study will be performed along the main Contzintla and Tlacolula rivers from Huayacocotla Anticlinorium (20°45'–20°49' N. Lat., and 98°34'–98°31' W), and consequently the fieldwork would involve identifying, describing, and sampling clastic facies (i.e., Facies 2 and Facies 3; Fig. 1C). The petrography will be carried out based on Gazzi-Dickinson method. A comprehensive approach by analyzing 300–600 points for around 20 coarse- to medium sandstone thin section samples will ensure a detailed and representative framework of the texture, and composition of the formation. The clastic facies analyses will gain insights into new data on the origin of sediments (i.e. the factors influencing genesis, and sedimentary processes), and the different input systems and source compositions with which the sediments may

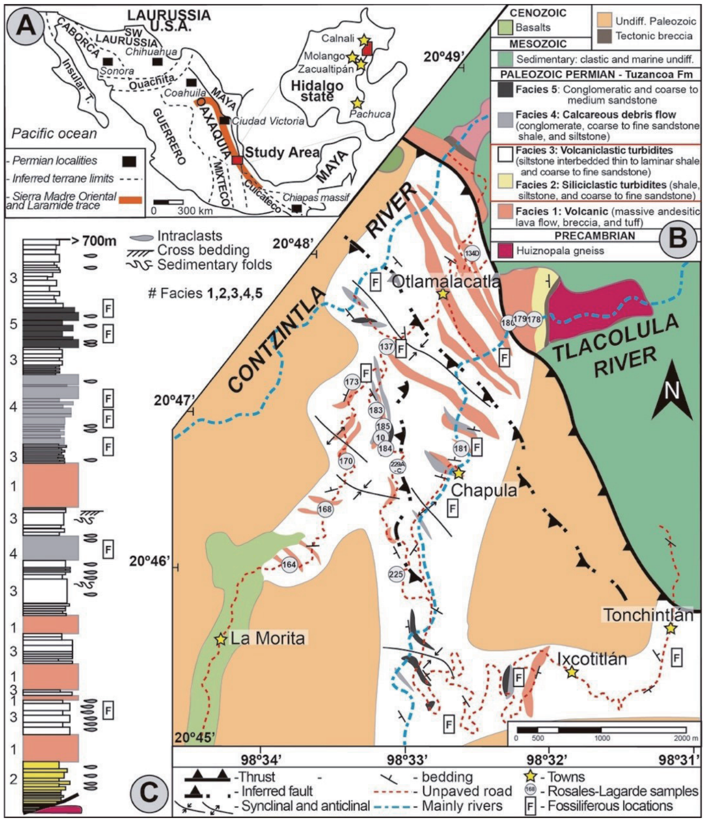

Fig. 1. (A) Mexican tectonostratigraphic terranes and location of study area in Hidalgo state, (B) geological map, and (C) simplified stratigraphic column and facies distribution (numbers on the left) of the Tuzancoa Formation (Modified from Rosales-Lagarde et al., 2005). Note. Facies 2 & 3 are the main primary focus of this work.

be associated. Additionally, the modal compositions will be interpreted, discussed, and compared, if required, to turbiditic rocks in other Permian basins (e.g., Guacamaya Formation, Tamaulipas).

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SUBMISSION GUIDELINES FOR ISSUE 77

It is best to submit manuscripts as attachments to E-mail messages. Please send messages and manuscripts to Yichun Zhang's E-mail address. Hard copies by regular mail do not need to be sent unless requested. To format the manuscript, please follow the TEMPLATE that you can find on the SPS webpage at http://permian.stratigraphy.org/.

Please submit figures files at high resolution (600dpi) separately from text one. Please provide your E-mail addresses in your affiliation. All manuscripts will be edited for consistent use of English only.

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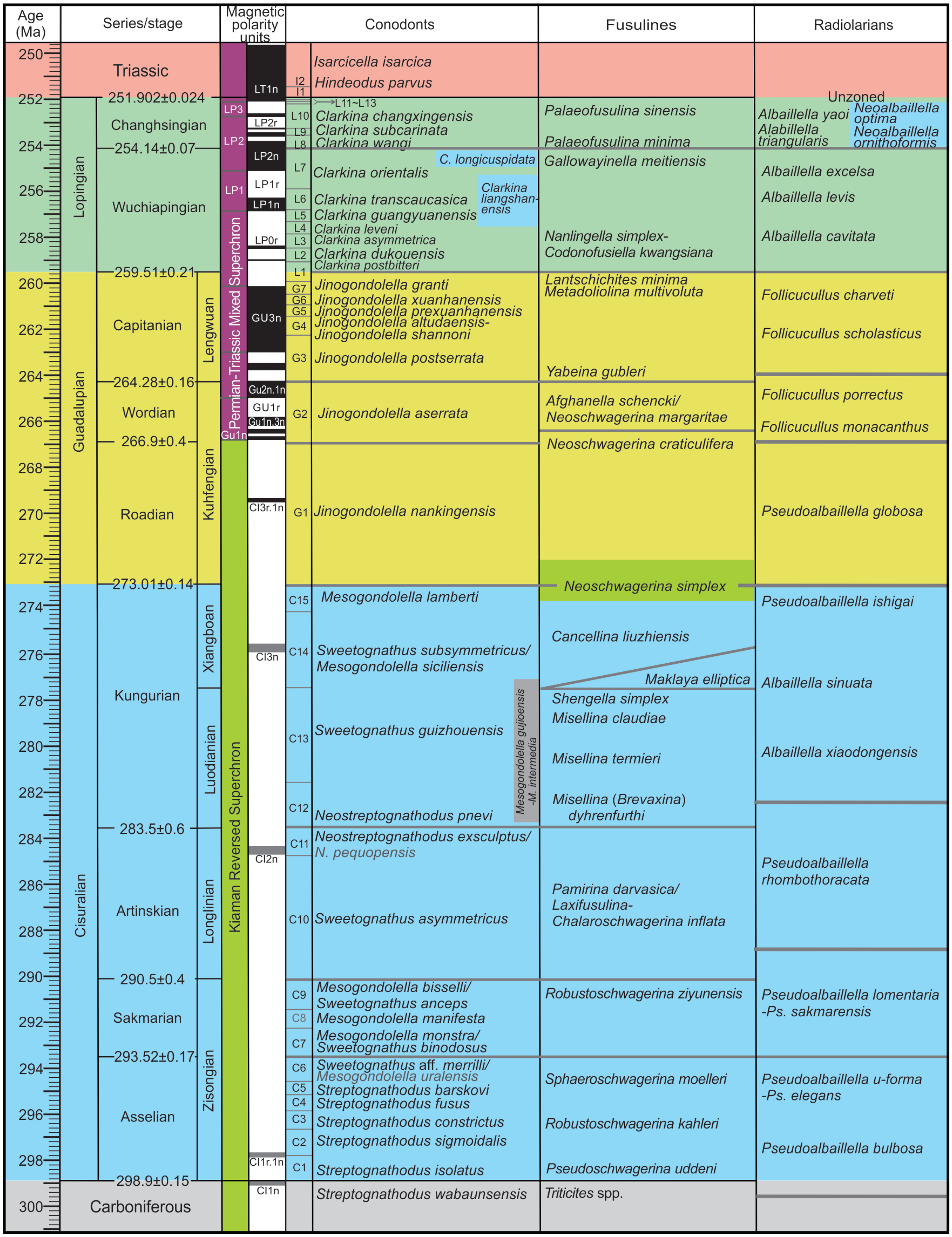
The deadline for submission to Issue 77 is July, 31, 2024



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