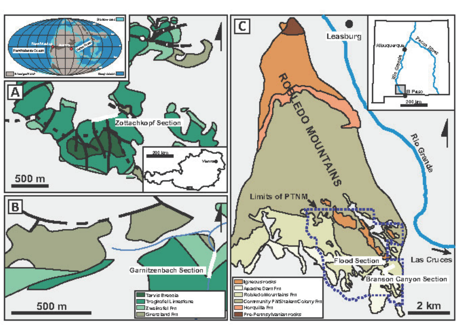
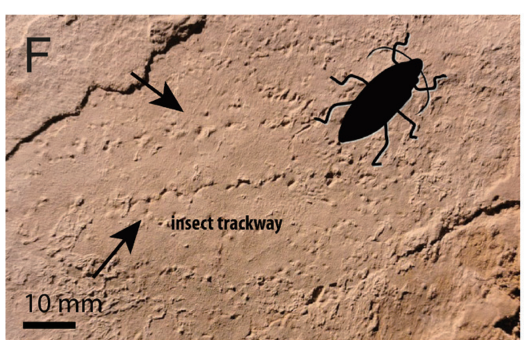
Permophiles

International Commission on Stratigraphy





Newsletter of the Subcommission on Permian Stratigraphy
Number 75
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Notes from the SPS secretary
Yichun Zhang

Introductions and thanks

As usual, the summer of every year is dedicated to my fieldwork in the remote region of northern Tibet. After finishing with success my fieldwork, I began to edit this issue of *Permophiles* with the Chair Lucia Angiolini and Vice-Chair Mike Stephenson via frequent email contacts in this hot summer.

This issue of *Permophiles* is special as it contains several perspectives, as it was done for the 50th issue published in 2007. In the past 16 years, SPS led by Charles M. Henderson, Shuzhong Shen and Lucia Angiolini has made great achievements (especially the establishment of Permian GSSPs). As many distinguished professors state in this issue, there are still many key scientific problems to be resolved. SPS encourages scholars to deal with these problems. Also, *Permophiles* is always an open platform for communications, exchange of ideas and research. I would like thank all contributors of this issue: Charles M. Henderson, Shuzhong Shen and colleagues, Spencer G. Lucas, Michael H. Stephenson, Joerg W.Schneider, Daniel Calvo González and colleagues, Daniel Falk, Chris Mays and colleagues, Marco Viaretti and colleagues.

Finally, as usual, I would like to keep drawing your attention to our SPS website https://permian.stratigraphy.org/, where you can find all issues of *Permophiles*, updated Timescales, presentation videos and news about the Subcommission on Permian Stratigraphy.

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This issue of *Permophiles* starts with the minutes of the SPS Business Meeting held at Lille, France on July 12, 2023. In the following contributions, Charles M. Henderson announces a working group to work on a base-Kungurian GSSP proposal with candidate Rockland Section in Nevada. Also, he announces the SPS Executive Second Term (2024-2028).

The second part of this issue is dedicated to the Permian Perspectives provided by Charles M. Henderson, Shuzhong Shen, Spencer G. Lucas, Michael H. Stephenson and Joerg W. Schneider. Charles gives suggestions to future *Permophiles* and task of SPS. He suggests that more attention should be paid on "time", including finishing the remaining base-Kungurian GSSP, restudy of GSSP, correlations of the Tethyan Permian time scale with International Scale. Shuzhong Shen reviews the GSSPs of the base of every Permian stage, including the research progresses and problems. This up-to-date review provide us the progress and future of Permian studies regarding the refinement and updating of Permian GSSPs. The digital timeline obtained by big data and artificial intelligence is a new way for establishing both Permian chronology and global correlations, as suggested by Shuzhong Shen. Spencer Lucas reviews the nonmarine Permian biostratigraphy and biochronology. He evaluated the potential in the application of fossil biota (microflora, macroflora, charophytes, ostracods, conchostracans, insects, bivalves, fishes, tetrapod body fossils and footprints) and other methods (isotopic ages, magnetostratigraphy). Conclusively, the nonmarine Permian chronology and correlation require further study and development. Michael Stephenson reviewed the recent research advances in Permian palynology since 2007. He highlights that the palynological biozones in Gondwana regions, such as Australia and South America have been calibrated by radiometric dating by CA-IDTIMS. This method is significant for establishing the correlations of palynostratigraphy between Euramerica and Gondwana. Joerg W. Schneider reviews the work of Nonmarine-Marine Late Carboniferous – Permian – Early Triassic Correlation Working Group in the past years and he lists the progresses performed, as well as the problems remaining to be resolved in the next future. I want to thank those distinguished professors for their significant contributions that will guide future Permian studies.

The third part of this issue is the working report of researches developed with SPS funding. Daniel Calvo González and his colleagues have evaluated the Lower Permian microfacies changes in both yjr Robledo Mountains of New Mexico, USA and the Carnic Alps of Austria, based on a refined biostratigraphy of conodonts from both regions. Their study confirms a pronounced glacioeustatic fluctuations during the Asselian. Daniel Falk reports the research progress of an international team in the Wolferode area with emphasis on the imprints of insects, tetrapods and jellyfishes. Chris Mays and colleagues introduced their research progress on the end-Permian mass extinction event based on materials from Tasmania. They highlight the significance of the Tasmania basin in evaluating the mass extinction event in high-latitude southern hemisphere.

In the following part, two fieldtrip reports are given by Marco Viaretti and Shuzhong Shen. Marco Viaretti and his colleagues report their fieldwork in Sultanate of Oman aiming at collecting brachiopods and conodonts in the Permian Qarari Unit. Shuzhong Shen and his colleagues reported a joint fieldwork of Sino-German cooperative group in Caaschwitz Quarry in central Germany. The fieldwork was designed to investigate the Permian-Triassic boundary interval as well as biotic and environmental changes across this boundary.

Finally, a meeting announcement is provided as to the next ICCP.

Future issues of Permophiles

The next issue of *Permophiles* will be the 76th 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 76 is 31 December 2023. 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

This *Permophiles* issue is the 75th issue, an important anniversary.

Inspired by Charles Henderson, who invited outstanding Permian workers to write "Permian Perspectives" for *Permophiles* issue 50 in 2007, I asked Charles Henderson, Spencer Lucas, Joerg Schneider, Shuzhong Shen, and Mike Stephenson to contribute with a special and original Perspective to the 75th issue, 16 years later. These experienced 2023 Permian workers were thus invited to write about the development in their own discipline, how these advances have improved the understanding of the Permian, the future directions of Permian research, and eventually the importance of *Permophiles* in building the Permian community and conveying Permian research. And they did. The main themes of their perspectives, which I warmly invite you to read, are 1) the need to complete the Permian Time Scale by defining the last GSSP (the base-Kungurian) and revising those of the Guadalupian; 2) the importance of integrating biostratigraphic studies based on multiple fossil groups with chemostratigraphy, magnetostratigraphy and geochronology data, and possibly do this based on big data and artificial intelligence; 3) the need to intercalibrate the marine lithofacies with non-marine records and solve the problems of correlating terrestrial Permian deposits with the marine Standard Global Chronostratigraphic Scale; 4) the need to solve correlations between the Tethys and the rest of the Permian world hampered by strong provincialism in the Permian; and 5) the great value of *Permophiles* which is regularly issued twice a year and contains many articles and contributions that allow global communication and discussion, and provide workers with a way to stay up-to-date.

This is one of the reasons why I think that this issue of *Permophiles* is of outstanding importance and really worth reading by the Permian Community. Another reason is that in this issue, the SPS Working Groups are revised and a new working group is announced in order to guarantee the progress of future research and the achievement of SPS priorities. The new Working Group is the Kungurian-base GSSP Working Group and you can read about it in the presentation by Charles Henderson. Furthermore, in this issue, Daniel Calvo González, Daniel Falk and Chris Mays present the results of their very interesting research that were in part funded by 2021 SPS funds, showing that supporting early career researchers is a good strategy to develop Permian studies.

During STRATI 2023, at Lille, France, 11th-13th July 2023 we had a SPS Business Meeting (you can read the Minutes by Mike Stephenson in this issue) and a session: SC10 Correlation of glacial events and extinctions: the Permian and beyond with 10 oral presentations (https://strati2023.sciencesconf.org/browse/session?sessionid=77948). Following the call published in *Permophiles* 74, SPS funded the Conference Registration fee (Student fee) for Marco Viaretti and Alexander Wheeler, who presented oral communications at Session SC10 at STRATI 2023.

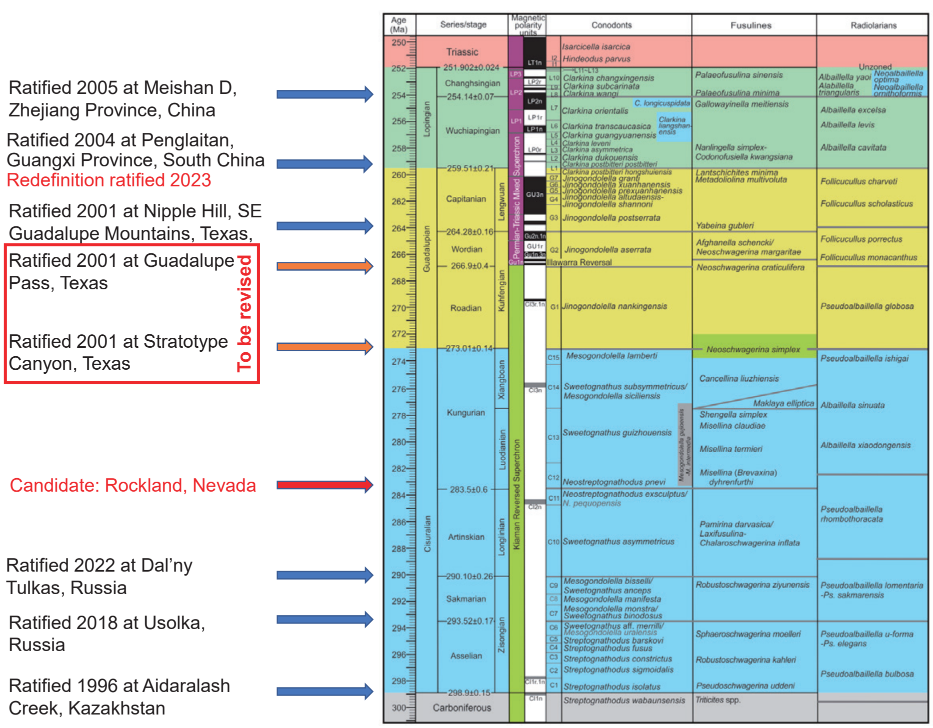
As referred to in some of the Perspectives articles in this issue, I would like to draw your attention to the progress made in finishing the Permian Time Scale. On May 1, 2023 the Subcommission on Permian Stratigraphy approved the proposal of the Standard Auxiliary Boundary Stratotype (SABS) for the base of the Wuchiapingian Stage of the Permian System at the Fengshan Section in China. On July 24, 2023, the SPS proposal for redefinition of the base of the Permian Wuchiapingian Stage GSSP was ratified by the IUGS Executive. The following figure represents the current state of the art of the Permian GSSPs.

To keep the Permian community informed of largescale initiatives of interest to IUGS and ICS, the webinar "The IUGS Deep-time Digital Earth Program" by Mike Stephenson was organized on June 12, 2023, live online through Zoom: https://permian.stratigraphy.org/Interests/DDE

We are planning a new webinar for October 24, 2023 "Progress, problems and perspectives for the base-Roadian and base-Wordian GSSPs" by Shuzhong Shen and Charles Henderson.

As always, please follow SPS and our initiatives!

My warmest thanks to Yichun Zhang, Mike Stephenson and all the contributors to this very interesting *Permophiles* issue.



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After Shen et al. 2019, 2020; Wu et al. 2020

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Working group leaders

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

2) Carboniferous-Permian-Early Triassic Nonmarine-Marine Correlation Working Group; Chair: Joerg Schneider.

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

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Subcommission on Permian Stratigraphy business meeting

A business meeting of the of the Subcommission was held during the STRATI 2023 congress, at Lille, France, 11th-13th July 2023.

Notes on the business meeting

Wednesday 12 July, 18:00 in Room Y, Congress Centre of Lille University 'Lilliad', Campus "Cité Scientifique"

AGENDA

- Introduction
- Short reports from the Chairs of the Working Groups: Charles Henderson, Mike Stephenson and Ausonio Ronchi on behalf of Jörg Schneider
- Subcommission plans for the coming year
- New working groups
- Report on the election of SPS officers for the next term (2024-2028) by Charles Henderson
- *Permophiles*
- Any other business

Details

Introduction

Lucia Angiolini welcomed people to the meeting.

Lucia Angiolini mentioned the need for two new working groups of the SPS

- To develop the GSSP for the base-Kungurian – to be led by Charles Henderson
- To deal with problems in relation to the Roadian and Wordian

The next SPS webinar will be about problems of the Roadian and Wordian and be led by Charles Henderson and Shuzhong Shen sometime in October.

Lucia Angiolini mentioned that two issues of SPS Newsletters *Permophiles* are to be published (*Permophiles* 75 in August 2023 and *Permophiles* 76 in January 2024). *Permophiles* 75 Special Issue will contain Permian Perspectives written by outstanding Permian workers as done for *Permophiles* 50 in 2007.

Lucia Angiolini emphasized the need to revise the Guadalupian GSSPs, in particular the base-Roadian and base-Wordian as a detailed documentation of the base-Capitanian has been recently published (Shen et al. 2022, Episodes 45(3): 309-331). In fact, the official GSSP papers for the Roadian and the Wordian were not published, although the GSSPs have been widely correlated for more than two decades.

Rockland section

Charles Henderson then talked about the Rockland section and the team that might be part of the working group including Charles Henderson, Luke Bratton, Kate Tierney, Tamra Schiappa, Walt Snyder, Dongxun Yuan, and Mike Reed.

Base-Lopingian GSSP at Penglaitan

Shuzhong Shen then presented the redefinition of the base-Lopingian GSSP at Penglaitan, Guangxi, South China. Shuzhong Shen also added information on the ongoing work about the Roadian and Wordian GSSPs.

Euramerica Gondwana correlation Working Group

Mike Stephenson discussed the new Euramerica Gondwana correlation Working Group. The group was set up to deal with issues such as

- Difficulties in identifying many of the Euramerican defined GSSPs (including the C/P boundary) in Gondwana
- Provinciality of the Permian
- The non-marine, cold climate nature of Permian Gondwana basins
- Different provincial 'taxonomies'
- Quality of data and information variation in different parts of Gondwana and Euramerica

Carboniferous – Permian –Triassic Nonmarine-Marine Correlation Working Group

Ausonio Ronchi on behalf of Jörg Schneider then discussed

the Carboniferous – Permian –Triassic Nonmarine-Marine Correlation Working Group.

Some notable progress:

• Radioisotopic ages produced by several members of the working group main in Czech, Germany, France and Russia. E.g. for the French St. Affrique basin by Poujol et al. 2022, and for the Karoo basin by Day et al. 2022

• Interdisciplinary cooperative research project on the world-famous Early Permian tetrapod track and skeleton locality Bromacker near Tambach-Dietharz village in the Thuringian Forest basin

• A German/UK/Jordan team did fieldwork in the Permian/Triassic transition at the Dead Sea of Jordan

• The Artinskian Warming Event: a change in climate and th terrestrial biota during the Early Permian by Marchetti et al., 2022.

Report on the election of SPS officers for the next term (2024-2028) by Charles Henderson

Charles Henderson mentioned that he was asked to chair a one-time subcommittee to determine whether the SPS voting members support a second term of Lucia Angiolini and Mike Stephenson as Chair and Vice-Chair of SPS following the next IGC.

Mike Stephenson
July 19, 2023

Working Group Announcement and Progress on the base-Kungurian GSSP proposal

Charles M. Henderson

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Introduction

As announced in *Permophiles* 74 (Angiolini et al., 2023) the Subcommission on Permian Stratigraphy plans to move ahead on a Kungurian GSSP proposal with Rockland Section, Nevada as the candidate. The only other candidate for some time now was the Mechetlino section in Russia. However, this section is no longer available owing to scientific sanctions by the IUGS because of Russia's invasion of Ukraine. In order to proceed with a proposal for the Rockland section it is necessary to strike a working group that will eventually vote on a proposal.

Working Group Announcement

I will Chair the working group that currently includes Kate Tierney (whole rock strontium isotopes), Luke Bratton (conodont strontium isotopes), Dongxun Yuan (conodonts), Mike Read (fusulinids), Benoit Beauchamp (carbonate sedimentology), Tamra Schiappa (ammonoids and regional stratigraphy), and Walter Snyder (expert on Nevada tectono-stratigraphy). Tamra and Walt both have considerable experience with this section. In addition, Kate worked on this section as part of her PhD. Mike Read worked on nearby sections as part of his PhD as well. I do intend to ask a few more people to increase the group to at least twelve researchers. If after reading this note you would like to volunteer please contact me.

Progress

The Rockland Section will likely become the GSSP (assuming positive votes by the WG and SPS and eventually ICS and IUGS) and the Mechetlino section will be discussed as a supplementary reference section. Henderson et al. (2012) and Chernykh et al. (2012) have proven the wide correlation potential of a base-Kungurian marked by the FAD of *Neostreptognathodus pnevi*. This conodont species can also be recognized in the Sverdrup Basin of the Canadian Arctic, the Delaware Basin of southern New Mexico and west Texas, and the Ziyun section in South China. Additional correlation tools include other fossils and strontium isotopes (both whole rock and of conodonts). Kate Tierney has been processing samples she collected a number of years ago for her PhD (she only processed into the Artinskian for her thesis); some new data has been completed recently. She will also run whole rock on two boundary samples I provided and Luke Bratton is currently processing conodonts for strontium isotopes from the same samples as part of his MSc. Benoit Beauchamp will provide some microfacies analysis of the Pequop Formation around the boundary interval; early indications suggest a shift in thermocline near the boundary. We also hope to report new information on fusulinids in a revised proposal. The base-Kungurian would correlate to a level within the red bed succession of the Arroyo de Alamillo Formation in southern New Mexico (Lucas et al., 2022).

Another aspect of a successful proposal is an indication that access and site protection are guaranteed. The site is freely accessible on Bureau of Land Management BLM forestry land. It is protected by the very fact that the section is near the top of a mountain. During a trip to Nevada in May this year I visited the California Trail Interpretive Center near Elko, Nevada and spoke with a BLM supervisory park ranger. There was considerable interest in adding signage, facilitating and identifying access to the Rockland section and also to a potential Standard Auxiliary Boundary Stratotype at Carlin Canyon (see Angiolini et al., 2023). More discussions will follow. During this same trip, Walt Snyder and I attended the Geological Society of America Cordilleran section meeting in Reno, Nevada. We each gave a presentation to sell the community to the value of having this GSSP. My talk was entitled "Finishing the Permian Geological Time Scale – by defining freely accessible stage boundaries in Nevada" (Henderson and Angiolini, 2023). Walt's talk was entitled "A field geologist's view of the Geologic Time Scale" (Snyder and Davydov, 2023). After the session we had lunch with James Faulds (Nevada Bureau of Mines and Geology State Geologist) and he is 100% in support of this GSSP plan. I want to thank Walt for facilitating this meeting and for convincing me of the value to present at the GSA section meeting.

The current plan is to have a draft of a proposal by the end of this calendar year in time for the next issue of *Permophiles* in which we would request comments from the community. Ideally, we would like to have this proposal completed (and ratified?) before the next International Geological Congress in Busan, Korea in August 2024.

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Snyder, W.S. and Davydov, V., 2023. A field geologist's view of the Geologic Time Scale. Abstracts with Program, GSA Cordilleran Section, Reno Nevada, May 2023.

SPS Executive Second Term (2024-2028)

All ICS officers technically retire at the IGC; the next one is at Busan, Korea in August 2024. ICS officers serve a four-year inter-congress period and all officers both in the executive and the subcommissions are eligible to serve two 4-year terms. ICS has made a call to all subcommissions to determine the need for an election or to determine the support of voting members for the executive to continue for another term. This is normally done by striking a committee.

Lucia Angiolini and Michael Stephenson will have served one term at the next IGC and have indicated that they would like to serve a second term. They asked me to chair a one-time subcommittee to determine whether the voting members support a second term. According to statutes, no formal election is required, unless there is overwhelming lack of support for a second term by Lucia and Michael. The SPS secretary is appointed by SPS executive and only needs to be willing to serve a second term.

The subcommittee was struck and consisted of myself and Tamra Schiappa. We asked SPS voting members to indicate whether they supported a second term or not. This was sent on May 28 and a reminder on June 30, 2023. Seventeen of nineteen voting members were eligible to express their opinion (excluding Lucia and Mike). Fourteen replies were received (82%) and all were favourable (3 voting members did not reply). Comments indicated that the current executive is very active and have done an excellent job. It was clear that SPS will be served well with a second term by Lucia Angiolini as Chair and Michael Stephenson as Vice-Chair. Yichun Zhang expressed interest in continuing in the role of Secretary.

With this note I declare that Lucia Angiolini and Michael Stephenson have the support of SPS to continue for a second term following the next IGC.

Charles Henderson
August 4, 2023

PERMOPHILES 75 PERSPECTIVES

Permophiles Perspective: The Permian System after 75 issues of Permophiles

Charles M. Henderson
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As Chairman of SPS and co-editor of *Permophiles* in 2007, I asked several experienced Permian workers to give their perspective on *Permophiles* and the Permian. Take a look back at issue 50 and see perspectives from Giuseppe Cassinis, Heinz Kozur, Ernst Leven, John Utting, and Bruce Wardlaw. They are very interesting and will provide part of the basis for my perspective below, since it seems, 16 years later, that I am one of the experienced workers contributing to a special 75th issue.

'Experience' is an interesting word – it is both a verb and a noun. We can experience an event as we encounter it, but experience is also the collective contact with facts and observation of events. Experience is the state of having been affected by knowledge through direct observation, application, or participation. It is the knowledge or skill that one has gained through doing something for a period of time – Malcolm Gladwell suggested it takes at least 10,000 hours. Einstein, in his book 'Ideas and Opinions', said "information is not knowledge – the only source of knowledge is experience". We live in a hyper-connected world where information is available in great abundance. Converting that information into knowledge means we have to actively engage with it to effect lasting change. We can acquire scientific understanding through experiments and tests after collecting accurate data – experience directs those tests.

It is likely that AI will alter some data into knowledge, but I still think that experience is needed to judge its veracity. Not all data are equal and some may be incorrect; it is not clear whether AI can correct those, but the work of Junxuan Fan and his team at Nanjing University is very promising. They have already published some very interesting results – check out OneStratigraphy online. The veracity of data was also the subject of the perspectives in *Permophiles* 50.

Ernst Leven (*Permophiles* 50, p. 6) said that 'progress on Permian studies is impressive indeed'. He then elaborated on a few problems that should be solved to affect even more progress. He said that 'biostratigraphic correlation faces a serious problem, which is usually ignored or unsolved because of poor understanding'. He was referring to morphology and parallelism in taxon evolution. He provided an example with *Polydiexodina* indicating that multiapertural fusulinaceans were nearly identical in the Capitanian of NA and Kubergandinian in the Tethys. He wrote that later investigations revealed that these two forms evolved from different ancestors at different times, thereby exhibiting parallel evolution. Another example he gave was *Sphaeroschwagerina* and *Pseudoschwagerina*, which are confined to the Asselian in the Urals. He postulated different ancestors to explain the occurrence of similar taxa dated as Sakmarian and Artinskian by conodonts in NA. However, if you have been reading recent issues of *Permophiles*, you will know that an example of parallel evolution in conodonts delayed the production of the Artinskian GSSP. We now know that *Sweetognathus whitei* occurs in upper Asselian cyclothems in association with abundant *Streptognathodus* and that a near homeomorph, *Sw. asymmetricus*, marks the base-Artinskian (Henderson, 2018). My student (Petryshen et al., 2020) used high resolution 3D tomographic scans and some mathematical magic to demonstrate that parallel evolution within two distinct lineages had occurred. It is noteworthy that Heinz Kozur (*Permophiles* 50, p. 5) noted that he was not convinced the Cisuralian *Sweetognathus whitei* was really identical with the holotype of this species. He was correct! Undoubtedly, there will be other such examples and we should work carefully to track these down. The fossil record provides an amazing recording of the past, but it is not always straightforward to interpret. Ernst Leven was particularly insightful when he suggested that the correlation potential and cosmopolitan distribution of conodonts may be overestimated. I am on record as saying that "conodonts are the most useful fossils in the world", but the best results always come with the full integration of the work by paleontologists studying multiple fossil groups, as well as with the work by geochemical and geochronological stratigraphers. Permian correlations between the Tethys and the rest of the Permian world remain an avenue for important additional research.

Despite the fact that I am getting close to the end of my active career, I remain excited by some of my recent new experiences with the Permian in Permianland (SW USA; see 1979 guidebook by that name edited by D.L. Barss). Over the past few years I am excited to be working with Spencer Lucas in Arizona, southern New Mexico and north-central Texas. It turns out Spencer is a good collector of productive conodont samples. He may have missed his true calling! We have written a couple of papers already (Lucas et al., 2022) and more to come. A paper in the works will discuss Olson's gap in tetrapod evolution and provide a link to the Kazanian of Russia. Spencer is a prolific writer and has provided tremendous service to SPS including co-editing with Shuzhong Shen "The Permian Timescale"; an excellent book published by the Geological Society (SP450). As we complete the marine Permian Time Scale, it is the intercalibration of marine lithofacies with the terrestrial realm that should become a major priority for SPS. Some outstanding outcrops occur in the Robledo Mountains of southern New Mexico and new ages and facies interpretations of the Abo Group are now published by one of my students, who is co-supervised with Benoit Beauchamp (Calvo Gonzalez et al., 2023; and this issue of *Permophiles*). I am also working with a team including Adam Huttenlocker (USC), Randy Irmis (University of Utah), Mike Read (Stephen F. Austin State University, Texas) and Jonathan Stine and Joshua Feinberg (University of Minnesota) on the amazing Upper Carboniferous-Lower Permian red bed succession in Valley of the Gods and Canyonlands in SE Utah, Permianland. In this beautiful region, marine limestones are very thin and probably mark only the maximum flooding surfaces. One paper is published (Huttenlocker et al., 2020) with more to come. There is a tremendous opportunity to integrate the vertebrate tetrapod record into the marine time scale in this region. The team is investigating vertebrate taxonomy and taphonomy, conodont and foraminiferal biostratigraphy, strontium isotopes, cyclostratigraphy and magnetostratigraphy. Similar multidisciplinary work is necessary to integrate the marine and non-marine records elsewhere, which is an obvious priority for SPS in the future. Just as important is the fact that current workers should make every effort to integrate these new records into their studies – even if it requires correlation changes.

Determining the age for the base Zechstein in Europe was a problem that Heinz Kozur considered a priority (*Permophiles* 50, p. 5). He said this problem related to the age of *Merrillina divergens* sensu stricto suggesting that is was likely late Wuchiapingian or early Changhsingian. Recently I got my first physical glimpse of the Zechstein during an excellent pre-STRATI 2023 field trip led by Stuart Jones and David Harper. During this trip of 'British Classics' in NE England and SE Scotland I also got to strike Hutton's unconformity from my bucket list. The Zechstein outcrop was near Sunderland. This includes one of the localities that Andrew Swift studied for conodonts as seen in his Palaeontographical Society (Swift, 1995) monograph. Here he recovered *Mesogondolella phosphoriensis* from the Marl Slate – a species later named *M. britannica* by Kozur (1997) with a specimen figured by Swift from the Sunderland area designated as the holotype. *Merrillina divergens* was recovered higher in the Magnesium Limestone. I think determining the age of these taxa remains a problem, and have suggested a collaboration with Stuart and David. *Merrillina divergens* and *Mesogondolella phosphoriensis* have been recovered from the Phosphoria Basin in USA and correlated with the Wordian (Wardlaw and Collinson, 1986). It is possible that the age of the lower Zechstein is Guadalupian! It will be important to consider the age of all Phosphoria units. Davydov et al. (2018) dated an ash bed in the "Meade Peak" as latest Capitanian suggesting that some Phosphoria units may range into the Lopingian.

In the 50th issue Perspectives there were at least three common themes, including 1) the excellent leadership enjoyed by SPS, 2) the great value of the many articles and communications in *Permophiles*, and 3) the many friendships and cooperative collaborations developed through our Permian research. I would like to echo these statements. Our current executive with Lucia Angiolini as Chair, Michael Stephenson as Vice-Chair and Yichun Zhang as Secretary are doing a great job! They did not miss a beat during the covid pandemic with a number of zoom seminars. Our executive is considering the future with new working groups and membership renewal. We should be proud that all of our issues of *Permophiles* are so informative. Some subcommissions are not as organized and have various communication approaches. SPS has a reputation of being among the best subcommissions. The regular nature of *Permophiles* is a great way for all of us to stay in touch with the latest accomplishments and progress. I have enjoyed many friendships and cooperative research and communications with colleagues around the world. Some are now gone, like Bruce Wardlaw, Heinz Kozur, and Yugan Jin. There are so many that I will not list them for fear of leaving someone off the list. But allow me to mention three that are especially close. Shuzhong Shen and I have been working together for 25 years and I consider him a close friend and trusted colleague. We have visited each other's homes, he has hosted me many times in China, we served together on an SPS executive, and we have published many papers together with more to come. We have influenced each other's career in many positive ways. Lucia Angiolini is also a special friend and trusted colleague and we have published together. We developed our friendship during my sabbatical in Milano in 2009 and my wife and I enjoyed an Italian Christmas with the Angiolini family. I have known Benoit Beauchamp longer than any other colleague – we were the odd couple (bilingual French Canadian and English only speaking introvert) setting off to the Canadian Arctic to begin our PhDs in 1984. Our friendship has had its ups and downs, but continues to endure. I am especially proud of some recent work we published with our students (see SEPM Special Publication 113). I value all of the friendships that I have made during my time studying the Permian and hope to make more. It is hard for me to imagine how I could have decided upon a more rewarding career. My first introduction to the Permian was by Professor Wilbert (Ted)

Danner who taught me Introductory Geology (in 1975-76) and later Carbonate Sedimentology including late Paleozoic rocks of the Chilliwack and Cache Creek groups. My first Permian research experience was during the summer of 1979 when I collected Middle Permian samples in the Canadian Arctic. That summer I lost a friend and mentor, but the material we collected set in motion my career direction. Dr. David Perry was a new professor of paleontology at UBC when he supervised my BSc thesis in 1978-79 and he joined me for a couple weeks in the Sverdrup Basin to collect brachiopod and conodont samples as my MSc supervisor. He died in a helicopter crash later that summer in the Rocky Mountains – I was still in the Arctic. The 'subordinate' conodont samples that we collected became the focus of my MSc with the help of a new researcher at the GSC in Vancouver – Dr. Mike Orchard. The rest as they say is history. But when I need to find a bit more energy and/or inspiration, I think of David.

So let me finish my perspective piece with some ideas on the problems that still need to be resolved by SPS. Some of them were identified in the 50th issue, but despite progress, they are still not resolved.

First and foremost we need to finish the Permian GSSPs, which was also pointed out 16 years ago. Only 'one' remains – the base-Kungurian (see my note in this issue). However, we are also revising base-Roadian and base-Wordian. The base-Artinskian was ratified last year and published this year and the base-Capitanian was ratified in 2001 and published after new research in 2023. The base-Wuchiapingian was recently revised. The details are important, but it is time to finish and address the various problems that can only be answered by looking at the entire rock succession. Defining the time scale has focused attention to boundary intervals and less on the succession between boundaries. It is time to finish, if not for us, then for the next generation of stratigraphers.

I think we need to focus more on the correlation of the Tethyan Permian time scale with the international standard – of course this is best done if the international marine scale is finished. We also need to better integrate the boreal marine succession and the Gondwana succession into the time scale. It is well known that the Middle and most of the Upper Permian exhibits provincialism that has hampered correlation. It is interesting that during the main phase of the late Paleozoic Ice Age (LPIA), conodont distribution seems to have been more cosmopolitan than after the LPIA. Do we fully understand the complexities of how climate affected the Permian world? What is the actual definition of the LPIA? Is there really a mid-Artinskian warming event? Is there a late Guadalupian mass extinction? Of course, to answer all of these questions and more, "timing" is paramount. More and more ash beds are being dated these days. Many of these new dates are challenging past correlations. Ultimately, this is a good thing. Neil Griffis has published some recent work (Griffis et al., 2019) in which he is dating flooding surfaces in Brazil, Namibia and South Africa and correlating these with deglaciation events. This has a significant potential to answer some of the LPIA questions posed above. I have stated many times of the value to integrate sequence stratigraphy with biostratigraphy, but now I should add geochronology to this mix. I am collaborating with Neil on some recent samples. Geochronologists like Neil (and Mark Schmitz and Roland Mundil) always express their ages by indicating the numerical precision of a radioisotopic date. Brad Cramer asked at STRATI 2023 whether it was possible to quantify chronostratigraphic uncertainty for timescale calibration. I don't have any answers, but it is a laudable goal since uncertainty occurs in all of our work from taxon identification to biofacies control on distribution of taxa.

There is some really good work being done to correlate the marine and terrestrial realms. Palynology (Michael Stephenson), insect biostratigraphy (Joerg Schneider and others), and vertebrate evolution (see above) will provide the terrestrial time lines. Finding conodont and fusulinid bearing marine limestones within these terrestrial units will allow integration with the marine time scale. Even better if we can find some ash beds to date any part of these successions. I also think making careful examination of the cyclicity of these units will assist resolution.

We have a time scale – it's nearly complete. My final appeal in this perspective is for everyone to use it. It might not be perfect and it might not use your favourite levels or names, but decisions have been made. If all of us really use these defined stages, we will better be able to answer the questions I mention above and many others. I think we will better understand the history of our Earth during the Permian with its major ice-age and extinctions? Once again, I say it is time we used it! I hear contrarian views from time to time, for example, 'it is Artinskian because it always has been' or 'these are Artinskian fusulinids and so cannot be Sakmarian'. Others have said 'the Barneston Limestone in Kansas is Artinskian because it has *Sweetognathus whitei* and all other fossils and geochemical signatures in it are therefore also lower Artinskian'. But our new time scale indicates that *Sw. whitei* is late Asselian. Feel free to substitute your own favourite unit (Elm Creek Limestone, Blaine Formation, Liangshan Mbr., Chihsia Fm. etc). This is not exclusive to the Permian-Triassic researchers I'm working with like to say 'these ammonoids are Olenekian and cannot be Induan' despite not having an official boundary. Sequence biostratigraphic geochronology might eventually demonstrate that some of these units are diachronous. When we make these statements, and we all do it a lot, what are we really saying? Are we saying I cannot use this international time scale? Are we saying it doesn't matter if I use it? Are we saying geologic time doesn't matter? I hope not.

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The Permian GSSPs and timescale: Progress, unsolved problems and perspectives

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The Permian Period is the last period of the Paleozoic Era and a few unique critical global events happened during this period. These include the Late Paleozoic Ice age (LPIA) from Pennsylvanian to early Cisuralian, the formation of the supercontinent Pangea and the semi-closed Paleo-Tethys Ocean, two large igneous provinces (the Emeishan and Siberian LIPs), and two biological mass extinctions respectively at the end-Capitanian and the end-Changhsingian. To resolve the tempos and understand causes of these global events, a reliable high-resolution timescale is essential. During the past three decades, the Permian timescale has been greatly improved (Shen et al., 2019b; Henderson and Shen, 2020). Eight out of nine Permian GSSPs have been established, only the GSSP for the base of the Kungurian Stage remains to be defined. Detailed proposals for the base-Kungurian GSSP (Chernykh et al., 2012) are available, so the general Permian chronostratigraphical framework at stage level is nearly completed, and great achievements have been made under the leadership and organization of the Subcommission on Permian Stratigraphy (SPS). At this time we can celebrate the great progress, it is also timely for us to think about what the unsolved problems are and what progress we expect in the Permian in the next decade.

1. GSSP progress and problems

First of all, I agree with the current SPS executives' strategy that we need to complete the only undefined base-Kungurian GSSP as the priority. The present two candidates for the base-Kungurian GSSP, the Rockland in Nevada and the Mechetlino Quarry sections in southern Urals, contain the conodont index species *Neostreptorgnathodus pnevi* (Chernykh et al., 2012). Similar species may be also present in the topmost part of the Liangshan Member of the Chihsia Formation in South China. General intercontinental biostratigraphic correlation is possible. However, the obvious unsolved problem is that both candidates lack additional markers. Unlike the other defined Permian GSSPs, high-precision CA-ID-TIMS dates are not available in both GSSP candidates. $^{87}Sr/^{86}Sr$ ratios based on the samples from both sections need to be analyzed. CAI values of the conodonts from the two sections are different and we are not sure whether different CAI values will affect the Sr isotope values or not. Fusulines are rare and basically local and difficult to be used for intercontinental correlation with the fusuline successions in the Paleo-Tethyan region. The range of the index species *Neostreptorgnathodus pnevi* is unknown.

Although all other GSSPs of the Permian System have been defined, quite a few have new problems that have emerged during subsequent studies. The GSSP for the base of the Permian System was defined (Davydov et al., 1998) with the FAD of the conodont *Streptorgnathodus isolatus* at Aidaralash, Kazakhstan. Unfortunately, very little new data are available since the GSSP was defined. The Usolka section is more commonly used for correlation because it contains multiple high-precision CA-ID-TIMS dates (Schmitz and Davydov, 2012). However, we are not sure how much difference in time there is between the FAD of the conodont *Streptorgnathodus isolatus* at Aidaralash and its first occurrence at Usolka in southern Urals. It seems plausible for SPS to organize new field works at the GSSP section at Aidaralash Creek, Kazakhstan in near future to confirm the correlation with the Usolka section in Russia.

The base-Sakmarian and base-Artinskian GSSPs were established at the Usolka and Dal'ny Tukas sections respectively in the southern Urals in Russia (Chernykh et al., 2020, 2023). The base-Sakmarian GSSP section is well exposed at Usolka and contains two conodont lineages (both *Mesogondolella* and *Sweetognathus*) with a few CA-ID-TIMS dates (Schmitz and Davydov, 2012). This is a well-constrained GSSP although the GSSP was placed at a level with distinct lithofacies change. The base-Artinskian GSSP section is relatively poorly exposed at Dal'ny Tulkas. Regular cleaning is necessary to keep the section workable. It is correlated by the FAD of the conodont *Sweetognathus asymmetricus* within the lineage *Sw. binodosus-Sw. anceps-Sw. asymmetricus* at the Dal'ny Tulkas section. The GSSP is well constrained by two CA-ID-TIMS dates (Schmitz and Davydov, 2012; Chernykh et al., 2023), which will provide precise absolute age calibration for the GSSP. Chemostratigraphy is basically not applicable because the rocks contain rich organic matter and clastic components, and were very likely altered (Zeng et al., 2012). Using the index conodont species *Sweetognathus asymmetricus* to define the GSSP is not ideal because the species was named based on the specimens from obviously younger strata at the Tieqiao section in the Laibin area, Guangxi Province of South China (Sha et al., 1990; Sheng and Jin, 1994; Shen et al., 2007; Sun et al., 2017). The occurrence of *Sweetognathus asymmetricus* from the main limestone member (above the Liangshan Member) of the Chihsia Formation at the Tieqiao section was mis-interpreted as early Artinskian by Sun et al. (2017), but was traditionally assigned to the earliest Kungurian in the Chinese timescale in terms of the associated fusuline *Misellina claudiae*, abundant *Pseudosweetoganthus costatus* as well as many other benthic fossils (Sheng and Jin, 1994; Shen et al., 2007). Thus, the solution for this problem is either to regard the index species as a long-ranging species from the base of the Artinskian to the lowest Kungurian or to perform further taxonomic studies based on the specimens from Dal'ny Tulkas and South China in order to biostratigraphically constrain the base of the Artinskian Stage more precisely. It will be necessary for Chinese colleagues to study where the base of international Kungurian Stage is in the Chihsia Formation in South China. This has been a persistent correlation problem between the fusuline-based Tethyan timescale (e.g., Leven, 1994) and the conodont-based international timescale (Henderson, 2018; Henderson and Shen, 2020). A big issue for all GSSPs in Russia is permission from the Russian authorities to collect samples and allow shipment of samples out of Russia.

The three GSSPs of the Guadalupian Series were ratified by IUGS in 1999 (Glenister et al., 1999), however, the official papers and the index species for the definitions from the GSSP sections have never been published and illustrated by the original authors. In order to solve the correlation of the Guadalupian Series between South China and North America, an international collaborative project supported by NSFC was carried out between 2015-2019. Large and high-resolution conodont, geochemical and ash samples from the three GSSP sections, that is the Nipple Hill, the Getaway Ledge and the Stratotype Canyon sections, were collected in the Guadalupe Mountains during last five-years of investigation (Ramezani and Bowring, 2018; Shen et al., 2020; Wu et al., 2020). The results indicate that the base-Capitanian GSSP at Nipple Hill contains abundant conodonts including the FAD of the index species *Jinogondolella postserrata*, thus, this GSSP has been formally published (Shen et al., 2022b). The GSSP has been well calibrated with the high-precision dates. The ash bed stratigraphically 20 m below the *Jinogondolella postserrata* Zone in the Bell Canyon Sandstone at Nipple Hill has been re-dated (265.46 ± 0.27 Ma) with the EARTHTIME ET535 mixed 205Pb-233U-235U tracer (Ramezani and Bowring, 2018). An ash bed from the lower part of the Pinery Member at Frijole has been dated as 264.23 ± 0.13 Ma and another ash bed in the lower part of the Radar Limestone Member is dated as 262.127± 0.097 Ma (Nicklen et al., 2015; Shen et al., 2020; Wu et al., 2020). The base-Capitanian GSSP was interpolated with an age 264.28±0.16 Ma (Wu et al., 2020). However, the GSSP was defined at about 0.5 m below the top of the Nipple Hill section. Therefore, the overlying successive conodont zones are not available. Chemostratigraphy is difficult because of the short, relatively restricted depositional environment of the carbonates and the underlying clastic deposits of the Bell Canyon Sandstone which are without marine fossils. No distinct chemostratigraphical signal is found around the base of the Capitanian Stage. Magnetostratigraphy at Nipple Hill is not available. At stratigraphically higher levels, the strata are well exposed at Frijole, about 2.9 km away from the GSSP section. High-precision U-Pb dates at Nipple Hill and Frijole provide good constrains for the base of the base-Capitanian GSSP (Wu et al., 2020). In addition, cyclostratigraphy for the Permian is also available in the Guadalupe Mountains, thus, the age can be calculated (Kerans et al., 2014; Shen et al., 2020; Wu et al., 2020).

After repeated collecting and processing for conodonts, we found that the base-Wordian GSSP has some unresolvable problems (Yuan et al., 2021; Lucas, 2023). 1) The samples from the GSSP do not contain conodonts except for some sponge spicules although repeated samples were processed by both labs in Calgary and Nanjing. 2) The original GSSP proposed in 1991 was at an outcrop about 3 km away, which is now on the private land. So the GSSP was moved to Getaway Ledge based on an observable lithologic correlation (Yuan et al., 2021). Thus, lithofacies changes may lead to the limestone unit being found to be diachronous. Samples from the original GSSP outcrop on the private land were also collected, but rare conodonts were found and they are not sufficient to recover a conodont lineage for the GSSP. 3) The limestone unit at Getaway Ledge is less than 10 m thick and is underlain by the thick Cherry Canyon Sandstone which is without marine fossils. The basal part of the limestone unit at Getaway Ledge still contains the conodont index species of the Wordian Stage, *Jinogondolella aserrata*, thus the FAD of the species is unknown in the Cheery Canyon Sandstone (Yuan et al., 2021; Lucas, 2023). Multiple ash beds were collected from the Cherry Canyon Sandstone above the Brush Canyon Member at Getaway Ledge. Unfortunately, none of them can be dated because no zircons are found in the ash beds (Wu et al., 2020). Thus, a Wordian GSSP is not workable in the Guadalupe Mountains area. South China may be a replacement for this GSSP because numerous continuous carbonate sections with both conodonts and fusulines are available. The problem is that precise correlation will be a challenge because the base-Capitanian and base-Roadian GSSPs are defined in the Guadalupe Mountains in North America. If the base-Wordian GSSP is defined in South China, probably a series of Standard Auxiliary Boundary Stratotype (SABS) are necessary for the three Guadalupian GSSPs both in South China and North America.

The base-Roadian GSSP (also base-Guadalupian) was originally defined by the FAD of the serrated *Jinogondolella* species which is easily distinguishable from un-serrated

Cisuralian *Mesogondolella* species. The species *Jinogondolella serrata* described from the Bone Spring Formation and Leonardian in West Texas (Clark and Ethington, 1962) and was first used as the index species for the base-Guadalupian GSSP, however, later it has been unanimously regarded as the synonym of *Jinogondolella nankingensis*. Thus, *J. nankingensis* with distinct serration on the anterior margin of the platform was used as the index species for the base of the Guadalupian. An obvious problem for this definition is that *Jinogondolella nankingensis* was named based on the specimens from the basal part of the Kuhfeng Formation at the Zhengpanshan section near Nanjing City (Jin, 1960; Shen et al., 2020), but it is defined for the base of the Roadian Stage in the Guadalupe Mountains in North America. Since all fossil records are not complete because of the Signor-Lipps effect, the correlation solely based on the FAD of the conodont species *Jinogondolella nankingensis* (= the North American J*inogondolella serrata*) between South China and North America clearly needs additional markers. Fortunately, two ash beds near the FAD of *J. nankingensis* at Nanjing was dated. The date 273.14 ± 0.13 Ma has been used as the absolute age for the base of the Guadalupian Series (Shen et al., 2020). Nonetheless, precise age and correlation problems may be still present for the base of the Roadian Stage because no high-precision dates are available at the Stratotype Canyon section in the Guadalupe Mountains and weakly-serrated *Jinogondolella* specimens are found from the horizons nearly 100 m below the FAD sample at the Stratotype Canyon section. Furthermore, typical serrated *Jinogondolella nankingensis* specimens have been recently found from the topmost part of the Chihsia Formation in South China. In addition, the FAD sample at the Stratotype Canyon section does not contain typical *J. nankingensis* except for rare juvenile specimens. Therefore, both the definition and correlation of the base-Roadian GSSP need to be re-investigated (Lucas, 2023). Sequence stratigraphy may provide additional correlation potential as Charles Henderson suggested.

The base-Lopingian GSSP is correlated by the FAD of the conodont *Clarkina postbitteri postbitteri* within the lineage *Clarkina postbitteri hongshuiensis→Clarkina postbitteri postbitteri→Clarkina dukouensis* at the Penglaitan section in the Laibin area in South China (Jin et al., 2006a). Two subspecies, *Clarkina postbitteri hongshuiensis* and *C. postbitteri postbitteri*, were distinguished taxonomically to meet the requirement that the GSSP must be placed in a continuous conodont lineage (Henderson et al., 2002) because there were serious debates whether *Jinogondolella granti* is the ancestor species of *Clarkina postbitteri* or not (Jin, 2000; Wang, 2000a, b, 2001, 2002; Henderson, 2001; Henderson and Mei, 2002;). Therefore, the separation of the two subspecies is more or less artificial and it is difficult for a non-conodont expert to distinguish them (Henderson et al., 2002). The section was situated along the bank of the Hongshui River. Unfortunately, a hydroelectronic power station was built at about 100 km downstream of the river, which elevated the water level 15 m above the previous level. Thus, both the Penglaitan GSSP and the auxiliary section at Tieqiao are flooded permanently. During the past decade, an international team made great efforts to search for a replacement section all over the world for the base-Lopingian GSSP. After a deep excavation along the bank of the Hongshui River, a new short outcrop was finally found and the outcrop contains the GLB interval. Meanwhile, the team also found a section in Fengshan, Liuzhou City, which contain a continuous conodont succession around the GLB. After intensive investigations into these two sections, the base-Lopingian Working Group finally used the new Penglaitan section as the new GSSP and the Fengshan section as the SABS. These two proposals (Shen et al., 2022c) have been recently ratified by the ICS and IUGS, and SPS respectively. In addition, the base-Lopingian definition was revised as well. It is correlated by the FAD of the conodont species *Clarkina postbitteri* because the previous two subzones, the *Clarkina postbitteri hongshuiensis* and *C. postbitteri postbitteri* subzones, cannot be resolved at the new GSSP section and *Jinogondolella granti* is associated with *Clarkina postbitteri* and many transitional forms are present in both sections. Thus, the lineage from *Jinogondolella granti→Clarkina postbitteri→C. dukouensis* has been confirmed at Penglaitan and Fengshan. The new correlation marker marks the evolutionary transfer from the Guadalupian *Jinogondolella* to the Lopingian *Clarkina* which can be recognized more easily and practically applied (Shen et al., 2022c).

The base-Changhsingian GSSP was established at the Meishan section D, which is correlated by the FAD of the conodont *Clarkina wangi* (Jin et al., 2006b). The section contains multiple ash beds, which were dated with the old MIT mixed 233U-235U-205Pb tracer. The base-Changhsingian needs an update of the CA-ID-TIMS dates slightly above the GSSP with the EARTHTIME ET535 mixed 205Pb-233U-235U tracer. The Permian-Triassic boundary is so far one of the best defined GSSPs because of the intensive studies on the EPME (Jin et al., 2000; Shen et al., 2011a; Yin et al., 2001). Numerous geochemical excursions including C, O, Sr, S, Hg, Ca, Zn, Li isotopes etc. were analyzed, and they all demonstrate distinct excursions at the EPME level (Cao et al., 2009; Xie et al., 2007; Shen et al., 2011b; Joachimski et al., 2012; Chen et al., 2016; Liu et al., 2017). In addition, high-precision CA-ID-TIMS dates are available, so the EPME is very precisely constrained within 61 ± 48 Kyr beginning at 259.941 ± 0.031 Ma at Meishan (Burgess, Bowring and Shen, 2014) and within 31 ± 31 Kyr at 251.939 ± 0.031 Ma at Penglaitan. A recent major advance is that high-resolution magnetostratigraphy across the PTB has been done at the Meishan section D (Zhang et al., 2021) and across the GLB at Fengshan (Shen et al., 2022c).

2. Global correlation of the Permian System

The formation of the supercontinent Pangea and the semi-closed Paleo-Tethys Ocean blocked the east-west equatorial ocean currents and caused strong provinciality of the marine faunas (Shi and Grunt, 2000; Mei and Henderson, 2001; Shen et al., 2013b; Ke et al., 2016). Strong provincialism in the Permian obviously makes the intercontinental correlation more difficult. The fusuline-based Tethyan timescale (e.g., Leven, 2004) is mainly used for the correlation among the Tethyan region. Fusulines from North America and southern Urals have strong endemism which are difficult to use for correlation with the Tethyan fusuline scheme. Thus, the conodont zonation became the most widely used biostratigraphic tool for Permian correlation. However, all fossils are incomplete in stratigraphic ranges, so their reliable correlation needs additional markers, in particular, for the long-range species used as the zonal species. For instance, *Jinogondolella nankingensis* has been identified as ranging from the Roadian to Capitanian (Sun et al., 2008), *Sweetognathus asymmetricus* has been proved to range from the base of the Artinskian to the lower Kungurian (Sun et al., 2017; Chernykh et al., 2023). In addition, conodont taxonomical issues have long been a problem among the conodont experts. There were two main methods to identify conodont species among the Permian community. Some colleagues identify the conodont species with a form-species concept that mainly uses the conodont morphological characters (e.g., outline, shape, size, presence or absence of serration, nodules, number of denticles etc.) of individual specimens to separate species. This method has caused some problems when the conodont population has strong morphological variations in form character. Another method is to identify the conodont species with a population concept that treats rare individual specimens with other species' characters as the intraspecific variations within the population (Wardlaw and Collinson, 1979; Mei et al., 2004; Yuan et al., 2017). If the sample-population method is used to identify other species in the Permian, then many identifications need to be revised. The two methods have been the main causes for most controversies in the Permian community. Therefore, establishing a reliable conodont succession based on clear phylogenetic evolution and obtaining additional physical markers will be ways to solve this problem. Furthermore, the marine conodont succession cannot solve the correlation between marine and terrestrial sequences.

Recently, high-precision CA-ID-TIMS dating provided great potential for precise correlation between both marine and terrestrial strata. The precision of the CA-ID-TIMS method now reaches 0.3‰ and it is higher than the resolution of most conodont zones (Schmitz and Kuiper, 2013; Burgess et al., 2014; Ramezani and Bowring, 2018; Shen et al., 2019a; Wu et al., 2021). However, ash beds are not always available in Permian strata. The base-Roadian, base-Wordian and base-Kungurian GSSPs lack geochronological constrains so far.

Chemostratigraphy has become another important tool for correlation since many geochemical signals reflect global changes in carbon cycle and redox conditions of the ocean system. Among them, the $^{87}Sr/^{86}Sr$ ratio is probably the most widely used geochemical proxy for stratigraphic correlation. The Permian $^{87}Sr/^{86}Sr$ curve showed a general decreasing trend from the beginning of the Permian and reached the minimum ~0.7068 in the Capitanian, then increased until the PTB with a value 0.707167 (McArthur et al., 2020; Wang et al., 2021). Therefore, the $^{87}Sr/^{86}Sr$ ratios can be used for interpolated ages. Based on the $^{87}Sr/^{86}Sr$ ratios 0.70743 to 0.70739, the base-Kungurian has been estimated at ~283.5±0.5 Ma (Chernykh et al., 2012). However, it is fundamental to evaluate the preservation state of materials used for seawater $^{87}Sr/^{86}Sr$ reconstruction. Calcitic brachiopod shells are considered as one of the best archives for capturing contemporaneous seawater $^{87}Sr/^{86}Sr$ due to their resistance to diagenesis. $^{87}Sr/^{86}Sr$ ratio of conodonts with low CAI is suggested to be used for estimating ages as well. But all these analyses are based on the assumption that the materials preserved the original seawater signals. Carbon isotopes also have been most commonly used for interpreting the global changes of carbon cycle. The EPME is basically everywhere marked by a distinct negative $\delta^{13}C_{carb}$ excursion of 3-8‰. However, this signal can be commonly altered by subsequent diagenesis. The end-Guadalupian mass extinction has been reported with a $\delta^{13}C_{carb}$ negative excursion of 1-8‰ (Wignall et al., 2009; Chen et al., 2011; Shen et al., 2013a), but subsequent studies indicate that the excursion is in different magnitudes and different horizons, therefore, very likely derived from diagenesis. Many C-, O-, Sr-isotope excursions have been reported from the Permian sequences in different sections, so far none of them can be proved to be globally correlative except for the PTB $\delta^{13}C_{carb}$ excursion.

Magnetostratigraphy is another important tool to realize the correlation between marine and terrestrial sequences (Hounslow and Balabanov, 2018). However, the reverse polarity Kiaman Superchron is a quiet Permo-Carboniferous interval with few polarity zones which can be used for correlation. The overlying Illawarra Mixed Superchron is marked by the Illawarra Reversal in the mid-Permian (very likely in the late Wordian), which is an extremely important marker for global correlation. However, this reversal has not been widely identified in different continents. The high-frequency magnetostratigraphic polarity zones within the Illawarra Mixed Superchron have great potential to establish a high-resolution magnetostratigraphic timescale for correlation between marine and terrestrial sequences from the late Guadalupian through the Lopingian. However, all these polarity zones need additional marker to constrain their precise ages (e.g., high-precision geochronology).

3. Digital timeline-a perspective from ICS

The above briefly reviewed progress and problems suggest that we have endless work to do to improve Permian correlation. The more we work on different makers and tools, the more problems we may have. There are grounds for optimism in that the Permian timescale has been greatly improved although many problems remain to be solved. ICS had an ambition to complete all GSSP work by the year 2008 before. Although great progress has been made, about 20 GSSPs still remain to be defined until now. In addition, many new problems for the established GSSPs emerged as further works are carried out. The problems we have encountered in the Permian are also present in all other systems. As the increasing number of stratigraphic sections being studied, we have seen more contradictions in performing large-scale stratigraphic correlations and establishing more precise geological timeline. This cannot be addressed easily by traditional artificial correlations. It is quite normal to have numerous contradictions when we correlate different sections because most of geologic records suffered subsequent alternations and all fossil records are incomplete.

Theoretically, all geological records have temporal and spatial properties and thus should be valuable for intercontinental and regional correlations. The 21st century has entered an age of the widespread application of big data and artificial intelligence. We realize that building a high-resolution geological timeline with big data and new tools is an urgent mission for stratigraphers and paleontologists. This should be the next main task for ICS to consider although completing the GSSP work will still be one of the priority works for ICS.

The new geological timeline program should bear the following characteristics (Shen et al., 2022a): (1) Supported by global stratigraphic databases, we should comprehensively collect all stratigraphic sections containing fossil records. Once the data are entered into the database, they are stored permanently and can be retrieved anytime to make full utilization of the comparative value of fossil records. (2) Using applied statistics, artificial intelligence algorithms, etc. to correct the incomplete nature of fossil records and obtain statistically optimal solutions for the ordering of stratigraphic information. (3) Combined with the geochronology, magnetostratigraphy, chemostratigraphy and cyclostratigraphy data, optimizing the correlation between each profile and greatly improved the correlation accuracy. (4) The database can be updated at any time, and finally, a geological timeline of any time interval can be automatically generated. Ultimately, as the data increase, the precision will become higher and higher, and human subjective factors will be significantly reduced, which will radically change our understanding of biological and geological events in Earth's history (Shen et al., 2022a).

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Permophiles Perspective: Nonmarine Permian Biostratigraphy, Biochronology and Correlation

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Introduction

Much of Murchison's type Permian section in Russia, and a significant portion of its equivalents farther west in Europe, are strata of nonmarine origin. However, it has long been agreed that a global timescale (the standard global chronostratigraphic scale, or SGCS) needs to be based on marine fossils in marine strata, not on nonmarine rocks and fossils. Nevertheless, during the last few decades much effort has been devoted to developing nonmarine Permian biostratigraphy, biochronology and correlations, well reviewed by articles in Lucas and Shen (2018) and by Schneider et al. (2020). Here, I assess the state-of-the-art of nonmarine Permian biostratigraphy, biochronology and correlation.

Nonmarine Permian World

Permian Pangea (Fig. 1) was a relatively diverse place in terms of climate and topography. Lower Permian glacial deposits represent the continuation of glaciations in southern Gondwana. Along the sutures of Pangea, huge mountain ranges towered over vast tropical lowlands. During the Middle and Late Permian, interior areas included dry deserts where eolian sands accumulated. Evaporites (particularly gypsum and halite)

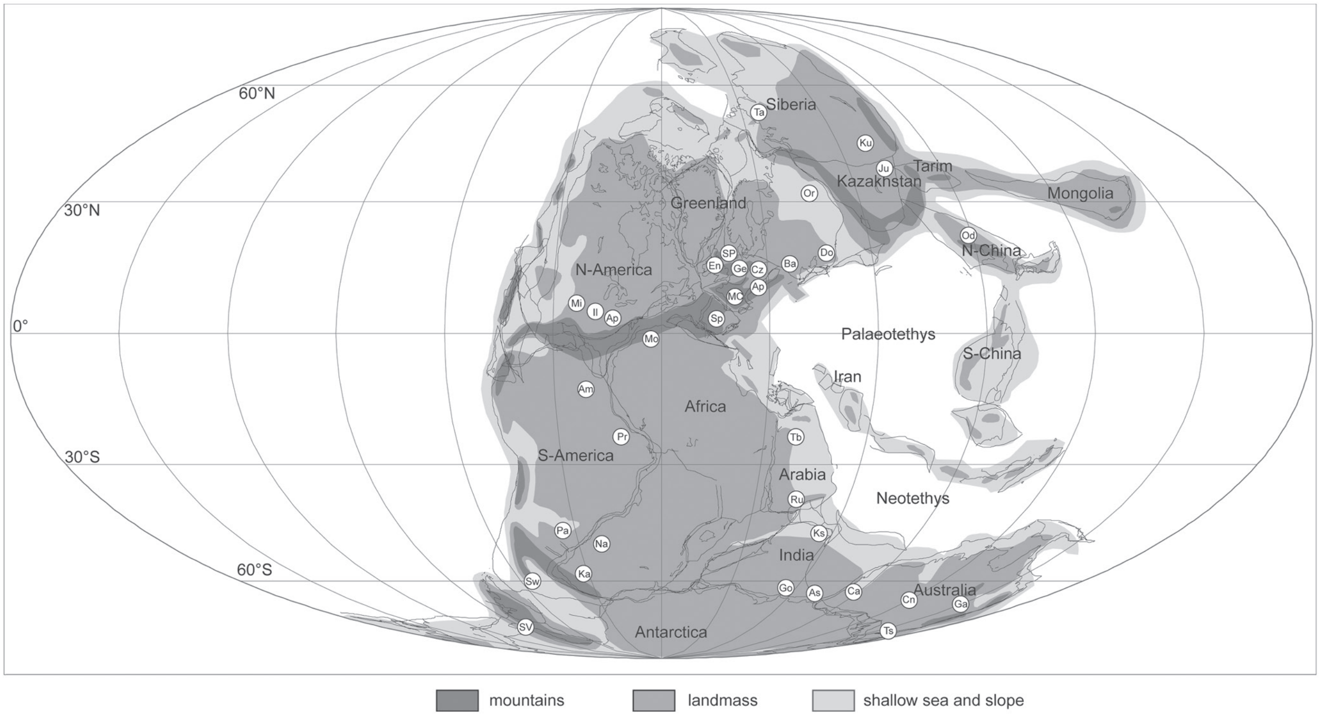

Fig. 1. Map of Pangea at 270 Ma (from Lucas et al., 2006) with the most important continental (nonmarine) Permian-Carboniferous basins indicated: Al: Alpine basins, e.g. Carnic Apls, Collio basin, Salvan-Dorénaz basin; Am: Amazon basin; Ap: Appalachian basin; As: Assam-Arakan basin; Ba: Balkan basins, e.g. Moesian basin, Resita basin, Sirina basin; Ca: Carnarvon basin; Cn: Canning basin; Cz: Czech basins, e.g. Intra Sudetic basin, Boskovice Graben, Bohemian basins; Do: Donezk basin; En: localities of Hopeman and Elgin; Ga: Galilee basin; Ge: German basins, e.g. Saar-Nahe basin, Thuringian Forest basin, Saale basin; Go: Godavari Valley basin, Il: Illinois basin; Mahanadi Valley basin; Ju: Junggur basin; Ka: Karoo basin; Ks: Kashmir basin; Ku: Kuznetsk basin; MC: basins of Massif Central and surroundings, e.g. Lodève basin, Autun basin, Bourbon l'Archambault basin, Commentry basin; Mi: Midcontinent basin; Mo: Moroccan basins, e.g. Chougrane basin, Khenifra basin, Tiddas basin, Souss basin; Na: Namibia region; Od: Ordos basin; Or: Orenburg region (Cis-Urals); Pa: Paraná basin; PB: Northern and Southern Permian basin; Pr: Parnaíba basin; Ru: Rub Al Khali basin; Sp: Spain basins, e.g. Puertollano basin, Cantabrian Mountains; SV: South Victoria Land, Trans Antarctic Mountains; Sw: basins of SW-South America, e.g. San Rafael basin, Paganzo basin, Golondrina basin; Ta: Taimir basin; Tb: Tabuk basin; Ts: Tasmanian basin.

deposited in the southwestern USA and northern Europe record the evaporation of hot, shallow seas that formed the most extensive salt deposits in the geological record. Perhaps the best testimony to the diversity of Permian Pangea can be seen in its fossil plants, which identify several floral provinces across the vast supercontinent (Cleal, 2018).

The Pennsylvanian and Permian are distinguished by a degree of continentality only matched by the last five million years of Earth history. Thus, Gondwana encompassed an area of about 73 million km^2 but was only about 15% covered by epi-continental seas, and Laurussia encompassed an area of about 65 million km^2 but was only about 25% covered by epi-continental seas. The exceptionally low sea level was due to the accumulation of water in polar and inland ice during the late Palaeozoic glaciations, little to no spreading activity of the mid-oceanic ridges and, possibly, to the elevation of the geoid because of thermal shielding by the huge landmass of Pangea.

As a result, Permian nonmarine lithofacies and biofacies are diverse and complex. Each of the nearly 100 Permian continental basins in Euramerica (Fig. 1) has its own lithostratigraphic subdivision, which in many cases can only be correlated over a few hundreds of square kilometers. Correlations are made difficult in the many basins that lack inter-basinal lithological marker horizons or marine intercalations, and by the sparse and scattered fossil content of many of the nonmarine Permian strata.

Microfloras and Macrofloras

Microfloras (palynomorphs) and macrofloras have long been used to establish the biostratigraphy of Permian continental deposits (see reviews by Stephenson, 2018; Cleal, 2018). An explosive diversification in the microfloral record during the Pensylvanian-Permian enables concurrent range zonations based on the first appearances, acmes and last occurrences of different associated forms. Although the environmental influence on macrofloras is reflected in the microflora, regional palynostratigraphic correlations within the same floral provinces or biomes are possible in the Permian, but correlations between different floral provinces remain imprecise.

The persistence of conservative Carboniferous hydro- to hygrophilous floral elements into Permian (local) wet biotopes and the local appearance of modern typical Permian meso- to xerophilous floral elements in the Carboniferous are among the well- known problems of Permian floral biostratigraphy (e.g., DiMichele et al., 2020; Bashforth et al., 2021). These issues and evident provinciality will continue to limit the use of plant biostratigraphy in Permian chronology and correlations.

Charophytes, Ostracods and Conchostracans

The oogonia of freshwater characeous algae (gyrogonites) fossilize and have some utility in the correlation of nonmarine strata, particularly in the Cretaceous and Cenozoic. However, the Permian record of charophytes is very poorly known (Lucas, 2018a, b). The only substantial record is from China, and the biozonation based on it needs to be tested with data from other regions. Much more will need to be learned about Permian charophytes before they can provide a useful biostratigraphy.

The use of nonmarine ostracods in Permian biostratigraphy is hampered by three factors: (1) freshwater ostracods are very simple in morphological features of the shell; (2) the state of preservation (lack of preserved muscle scars and deformation, including complete flattening during sediment compaction) very often prevents any precise identification; and (3) their nearly hopelessly oversplit alpha taxonomy. I thus doubt that nonmarine Permian ostracods will ever provide a robust biostratigraphy at even regional scales.

Conchostracans are bivalved crustaceans whose fossils have been employed in some non-marine Permian correlations. They have a very high distribution potential because of their minute, drought resistant and wind-transportable eggs, and they often form mass accumulations in lacustrine lithofacies. Hence, conchostracans are some of the most common animal fossils of the continental Permian. Nevertheless, the time ranges of many Permian conchostracan species have not been well established, and much alpha taxonomy needs to be resolved (Schneider et al., 2020). If these obstacles can be overcome, conchostracans may contribute to regional and, perhaps, global nonmarine Permian correlations.

Insects

An updated insect zonation for the late Pennsylvanian to early Permian based primarily on blattids (cockroaches) has a time resolution of 1.5 to 2 Ma (Schneider et al., 2020). The zonation is based on the morphogenetic evolution of lineages of time-successive species of three genera of spiloblattinids. New reports of spiloblattinid zone species in nonmarine strata intercalated with conodont-bearing marine strata in North American basins could be one key to direct biostratigraphical correlation of continental Permian strata to the SGCS. Insects provide a robust biostratigraphy of Lower Permian strata, and I expect that biostratigraphy will continue to be refined with new discoveries.

Bivalves

Nonmarine bivalves, including the anthracosiids, palaeomutelids, and some myalinids (brackish water), had a worldwide distribution during the Permian. Some biostratigraphic correlations have been based on these bivalves (e.g., Eagar, 1984), but their alpha taxonomy seems extremely oversplit, as most variation is ecomorphophenotypic, not interspecific, in origin. Furthermore, it is unlikely that the stratigraphic ranges of many nonmarine Permian bivalves are well established (e. g., Lucas and Rinehart, 2005). This and the taxonomic problems should make us very cautious in using nonmarine bivalves for Permian biostratigraphy, and I am not optimistic that they will contribute substantially to reliable correlations in the future.

Fishes

Fishes have never provided a robust biostratigraphy in nonmarine strata. This is because nonmarine fishes and their fossils are limited to specific lithofacies and locations, so that their record is dominated by facies-control and endemism. Permian (nonmarine) xenacanth shark teeth have been applied to regional correlations between some adjacent European basins, but their wider use is limited because the migration of fishes is restricted to river systems that connected the basins. Thus, for example, the fish zonation of Zajic (2000) is actually a local ecostratigraphy of some Bohemian basins, not a robust biostratigraphy. The nonmarine record of Permian fishes will likely make few if any contributions to broader correlations.

Tetrapod Footprints

Permian tetrapod footprints are known from localities in North America, South America, Europe, Asia and Africa, and attempts to use footprints to correlate nonmarine Permian strata have a long tradition, especially in Europe (Voigt and Lucas, 2018; Schneider et al., 2020). Footprints provide a global Permian biochronology of three time intervals (biochrons), much less than the 11 time intervals that can be distinguished with tetrapod body fossils, though perhaps two additional footprint biochrons may be recognized in the Middle Permian after more research. Thus, the Permian tetrapod-footprint record provides some far-reaching correlations, but these will always be at a relatively coarse level of temporal resolution.

Tetrapod Body Fossils

Permian tetrapod (amphibian and reptile) body fossils have long provided a basis for nonmarine biostratigraphy and biochronology (Lucas, 2018c). The most extensive Permian tetrapod (amphibian and reptile) fossil records come from the western USA (New Mexico-Texas) and South Africa. Their correlation to the SGCS and its numerical calibration is relatively straightforward in the Early Permian, as the Texas Lower Permian red bed section has marine intercalations that yield fusulinids, conodonts and/or ammonoids that allow for marine-fossil-based ages to be assigned. Correlation of the Middle-Late Permian tetrapod record to the SGCS is aided by intercalated marine strata in the Russian section and radioisotopic ages from the Karoo basin the South Africa. A global set of 11 Permian faunachrons is based on the American Southwest (Early Permian) and Karoo basin (Middle-Late Permian) records. Provincial tetrapod biochronologies exist for western Europe (based primarily on aquatic/semi-aquatic amphibians) and the Russian Uralian basin.

Tetrapods are the taxonomic group that provides the most detailed chronology and correlations of Permian nonmarine strata, and they hold great promise for further refinement. However, a major threat to such refinement is cladistic taxonomy, a non-Darwinian method that hypersplits the taxa to undermine their use in broad correlations (see, for example, the discussion by Lucas, 2018c of the cladistic taxonomy of *Dicynodon* and related taxa). If cladistic taxonomy does not prevail, tetrapod biostratigraphy should produce more refined nonmarine Permian correlations in the future.

Isotopic Ages

Many radioisotopic ages are available in nonmarine Permian stratigraphic successions, especially in the German Rotliegend and related strata in France and Italy (Schneider et al., 2020). Many of these are old K/Ar ages of questionable precision, but recent work is providing more reliable Ar/Ar and U/Pb ages for some igneous rocks intercalated with nonmarine Lower Permian strata, and DZ ages for some of the Permian nonmarine sediments. These numbers can provide direct calibration of the nonmarine fossil biostratigraphies of the Permian rocks and hold great promise for yielding a more precise numerical calibration of nonmarine Permian biostratigraphy than can be directly achieved for the Permian SGCS. The challenges lie in cross-correlating nonmarine Permian biostratigraphy to the SGCS so that all the ages can be combined to produce a more precise numerical timescale for the Permian.

Magnetostratigraphy

Most of Permian time has long been considered an interval when there was little or no reversal activity of the Earth's magnetic field. Thus, all of Early Permian and some of Middle Permian time comprise the latter part of the Carboniferous-Permian reversed polarity superchron (also called the Kiaman superchron). The field began to reverse frequently during the Middle Permian, and this begins the Permian-Triassic mixed superchron. The initiation of the superchron is usually referred to as the Illawarra reversal.

The Illawarra reversal thus has been taken to provide an important datum for correlation in both marine and nonmarine Permian strata. Thus, for example, its presence in the Russian Tatarian has been used to directly correlate the Russian nonmarine section to the SGCS. However, as Lucas (2017) noted, the age of the Illawarra reversal in the SGCS has not been firmly established. It is generally considered Wordian, though current estimates range from earliest Wordian to early Capitanian (cf. Hounslow and Barabanov, 2018). This needs to be resolved with marine biostratigraphy before the correlation between the SGCS and nonmarine Permian records of the Illawarra reversal can be considered certain.

Prospectus

A diversity of biostratigraphic methods is available for nonmarine Permian chronology and correlation that need further development. In particular, sound alpha taxonomy based on neo-Darwinian principles and well-established stratigraphic ranges are needed for many fossil groups. A plethora of radioisotopic ages in nonmarine Permian rocks can be directly related to much nonmarine Permian biostratigraphy. And, in Middle-Upper Permian strata, magnetostratigraphy provides another correlation tool. All three data sets for the correlation of nonmarine Permian strata—biostratigraphy, radioisotopic ages and magnetostratigraphy—need to be integrated and cross correlated to the marine timescale. Only then can a better understanding of Permian Earth history on land and sea be achieved.

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Advances in Permian palynology since 2007: a review

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Background and introduction

Since this is a review concerned mainly with the chronostratigraphy of the Permian, it will concentrate on the use of palynology in stratigraphy and in the elucidation of aspects of Permian geological history and geology, rather than on palynological taxonomy. Palynological biostratigraphy (or palynostratigraphy) is the use of palynomorphs (defined as organic-walled microfossils 5–500 microns in diameter) in correlating and assigning relative ages to rock strata. As such, it is a branch of biostratigraphy and follows the rules of biostratigraphic practice: for example, those set out by Rawson et al. (2002).

The Permian has a number of distinct and recognisable events related mainly to the development of land plants. Amongst the most important changes in land plants is the replacement, near the end of the Carboniferous, of arborescent lycophytes by arborescent tree ferns, with arborescent lycophytes only persisting into the Guadalupian in China. The arborescent horsetails also declined by the end of the Carboniferous. In the Permian, a great variety of new seed plant groups appeared such as cycads, ginkgos, voltzialean conifers and glossopterids. The latter are important palaeobotanical biostratigraphic markers for the Permian of Gondwana and include several hundred species. It is estimated that by the Lopingian about 60% of the world's flora consisted of seed plants (Gradstein and Kerp 2012).

These big evolutionary changes in plants, modified by local and regional effects, are responsible for the palynological succession that provides opportunities for subdivision on which palynostratigraphic schemes are built. However, the pronounced phytogeographical differentiation of the Permian has an effect on palynostratigraphy, such that schemes differ considerably across Pangea and correlation between schemes is even now tentative or incomplete. In the Gondwana phytogeographical province, for example, it is difficult to correlate to the standard Permian stages; and the Carboniferous–Permian and Permian–Triassic boundaries are not precisely correlateable into Gondwana basins using palynology (Stephenson, 2008, 2016). Until recently, progress in correlation was hampered by the lack of fundamental stratigraphic standards such as stage Global Stratigraphic Sections and Points (GSSPs); however, since 1997 (Jin et al. 1997; Henderson et al. 2012) important GSSPs have been established within the Pennsylvanian – Permian succession, including all the Permian GSSPs, except for the Kungurian (SPS website: https://permian.stratigraphy.org/gssps).

Developments since 2007

The main developments in palynostratigraphy since 2007 relate to the radiometric dating of palynological biozones which has gone a long way to resolving the problem of calibrating palynozones, mainly in Gondwana. Most progress has been made in two geographical regions: South America and Australia. In other areas the main progress has been in taxonomic - palynostratigraphic studies of key areas; examples include palynology of southern African coal seams (Goetz and Ruckwied 2014; Ruckwied et al., 2014, Barbolini and Bamford, 2014); and Permian-Triassic palynology in the key sections of the Salt Range of Pakistan (Hermann et al., 2012).

Updates in Australian palynostratigraphy

Australia has some of the best documented Permian basins in Gondwana, but much of the succession is nonmarine. In the past, calibration of the most widely used local Australian palynostratigraphic scheme (Price, 1997) to the global timescale was indirect and very difficult, having traditionally relied on correlations from relatively sparse, high-latitude, marine strata, within which ammonoids and conodonts are rare, fusulinids are unknown, and much of the other fauna (brachiopods, bivalves) is endemic. Tie points are rare and often tenuous: one example is the record of a single specimen of the ammonoid *Cyclolobus persulcatus* from the Cherrabun Member of the Hardman Formation, in the Canning Basin, Western Australia, dated as 'post-Guadalupian' by and 'Capitanian–Dzhulfian' (see Foster and Archbold, 2001 for details). However in eastern Australia, the Permian succession contains felsic ash beds, many of which contain zircons. Ash beds are rare in Western Australia, but some have been found in the Canning Basin. In the last decade fieldwork has involved sampling ash beds for radiometric dating, coupled with sampling of adjacent sedimentary rocks for palynomorphs, mostly from cores and coalmines in the Sydney, Gunnedah, Bowen and Galilee basins in eastern Australia, and core in the Canning Basin in Western Australia (Fig.1). Dating zircons involved Chemical Abrasion-Isotope Dilution Thermal Ionisation Mass Spectrometry (CA-IDTIMS) for U-Pb dating. The resultant radioisotopic dates, with associated palynostratigraphic determinations, permit the direct calibration of the Price (1997) scheme to the numerical timescale.

Several papers and reports describe early results (Mantle et al., 2010; Smith and Mantle 2013; Nicoll et al., 2015, 2017; Bodorkos et al., 2016; Laurie et al., 2016), but a convenient summary is that of Smith et al. (2017). In broad terms the effect on Permian Australian palynozones has been significant with some zonal boundaries in the Permian shifting by as much as six million years. Revised dates for the Permian palynozones can now be applied to all Permian basins across Australia, including the Perth, Carnarvon, Canning and Bonaparte basins (along the western and northern continental margins), the Cooper and Galilee basins (in central Australia), and the Bowen, Gunnedah and Sydney basins (in eastern Australia).

In summary, the following changes are suggested for the Cisuralian of the Permian:

• APP3 (Price, 1997) zone is younger than previously calibrated

• APP2 zone has a greater duration, starting earlier and ending later, than previously determined.

• the top of the *Pseudoreticulatispora confluens* (APP1.22)

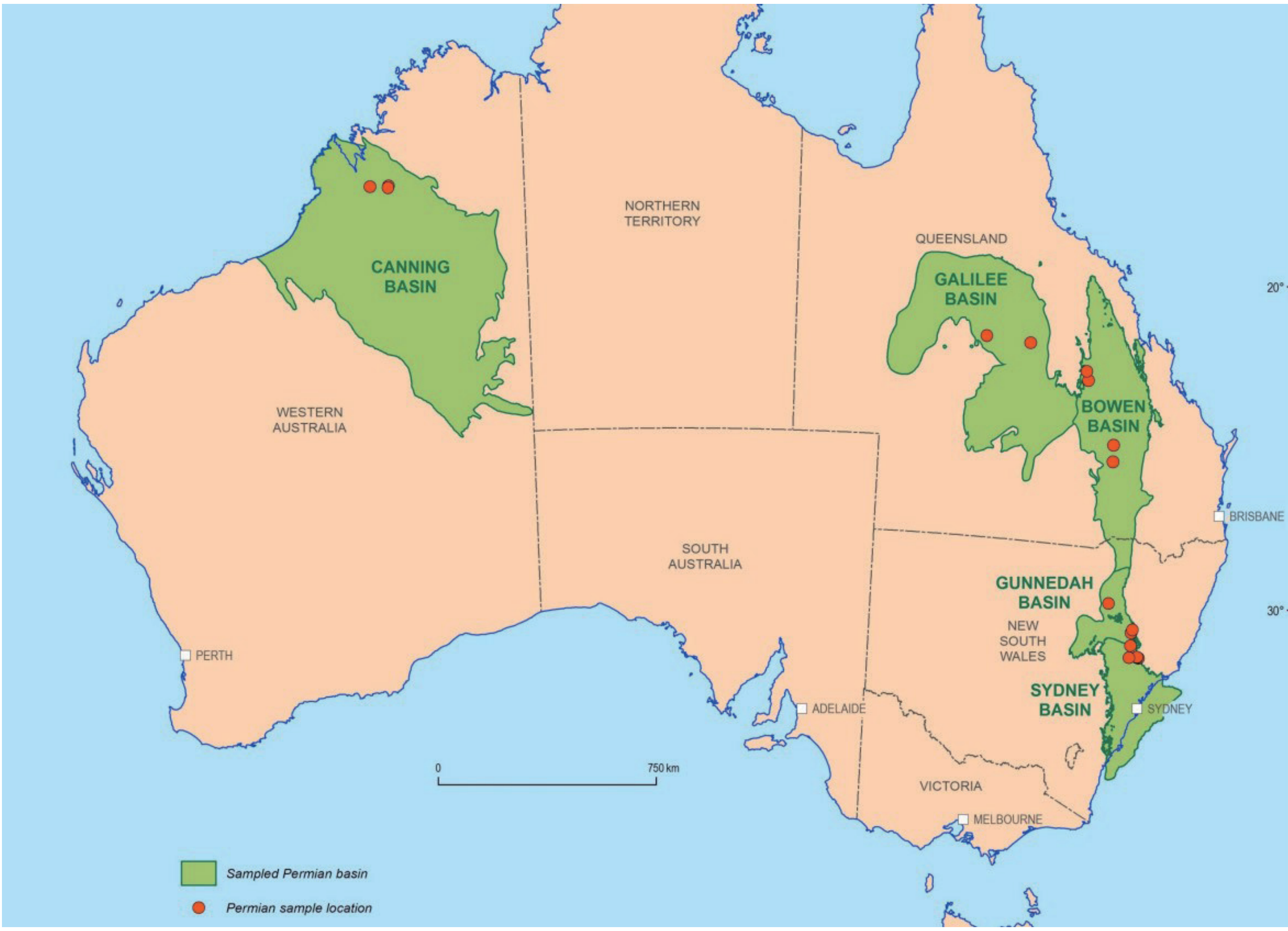

Fig. 1. Map of Australia showing Permian sampling locations. From Smith et al., 2017.

zone lies in the late Asselian;

• the top of the *Pseudoreticulatispora pseudoreticulata* (APP2.1) zone lies in the middle Artinskian;

• the top of the *Microbaculispora trisina* (APP2.2) zone lies in the early Kungurian;

• the top of the *Phaselisporites cicatricosus* (APP3.1) zone lies in the late Kungurian.

As detailed by Laurie et al. (2016) and Bodorkos et al. (2016), the results for the Guadalupian and Lopingian of Australia indicate that these Middle and Late Permian palynozones are significantly younger than previously suggested. The recalibrations indicate:

• the top of the *Praecolpatites sinuosus* (APP3.2) zone lies in the early Roadian;

• the top of the *Microbaculispora villosa* (APP3.3) zone lies in the middle Roadian;

• the top of the *Dulhuntyispora granulata* (APP4.1) zone lies in the Wordian;

• the top of the *Didecitriletes ericianus* (APP4.2) zone lies in the early Wuchiapingian;

• the entire *Dulhuntyispora dulhuntyi* (APP4.3) zone lies within the Wuchiapingian; and

• the top of the *Dulhuntyispora parvithola* (APP5) zone lies at or near the Permian−Triassic boundary

These recalibrations are summarised in Fig. 2.

South America

Calibration of palynostratigraphic zones by radiometric dating has progressed recently in four basins: the Tarija and Chacoparana basins in northern Argentina, the Paganzo in central western Argentina, the Claromeco Basin in eastern Argentina, and the Paraná and Amazonas basins in Brazil. There are a number of basin-specific palynostratigraphic schemes, but in general, the biostratigraphy of the basins is difficult to relate to the international stages of the Carboniferous and Permian because of the scarcity of marine faunas. Since 2007, the most marked progress has been made in integrating radiometric dates with palynological biozones, allowing limited–not always reconcilable–calibration of the latter with the international scale. Amongst the most important of these studies since 2007 are those of Césari (2007), Guerra-Sommer et al. (2008), Césari et al. (2011), Mori et al. (2012) and di Pasquo et al. (2015). In the first of the studies, Césari (2007) noted radiometric dates in the San Rafael Basin in central western Argentina and in the Paraná Basin in southern Brazil that suggested numerical ages for biozones established by Césari and Gutiérrez (2000), and Souza and Marques-Toigo (2003) in those basins, respectively. So the Lueckisporites–Weylandites Assemblage Biozone of Césari and

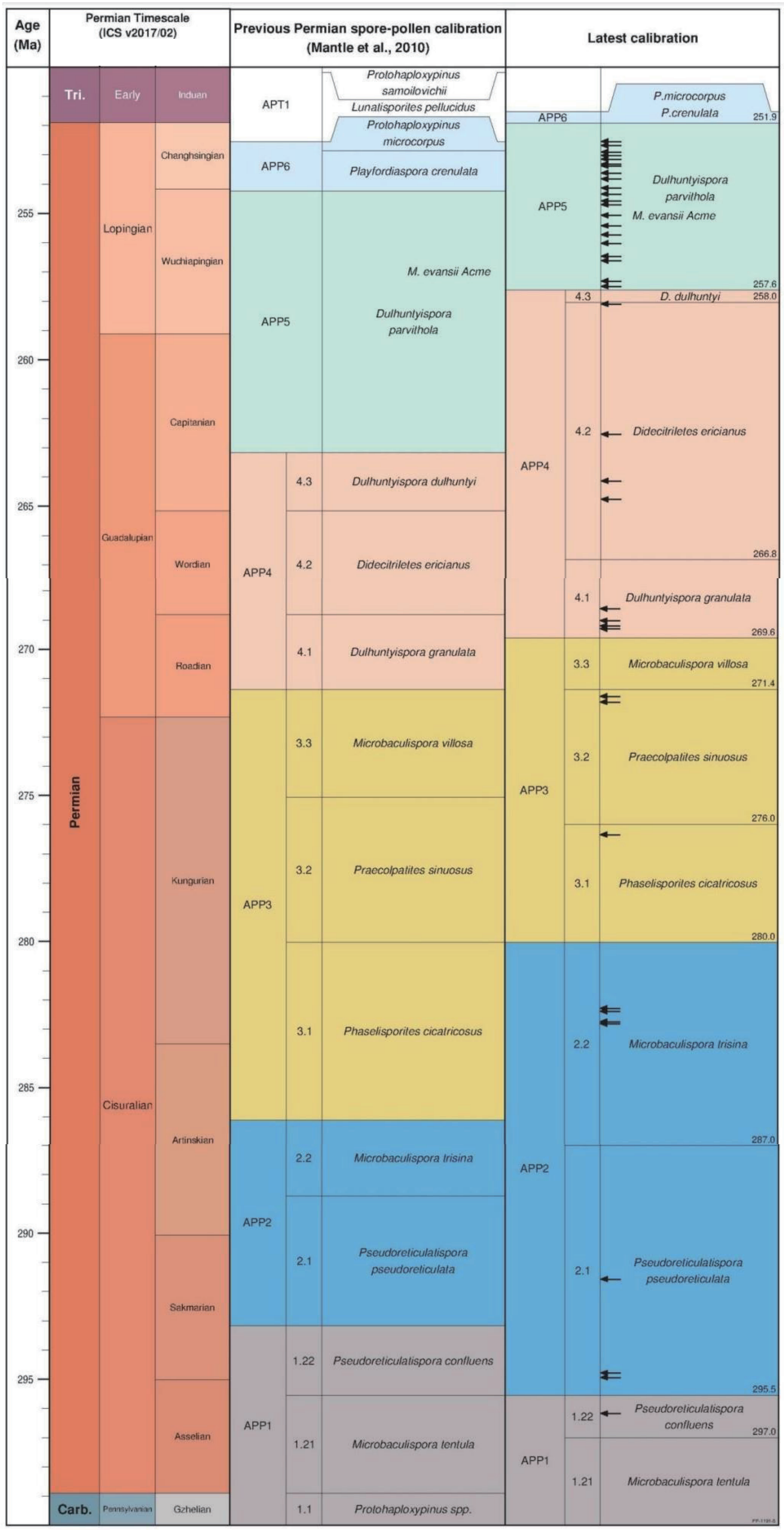

Fig. 2. Revised calibration of Permian palynostratigraphy in Australia. Each arrow represents a biostratigraphically controlled U–Pb zircon date obtained via CA-IDTIMS and interpreted to represent the depositional age of the sampled tuff layer. From Smith et al., 2017.

Gutiérrez (2000) in the San Rafael Basin contains a horizon dated at 266.3±0.8 Ma (Wordian), while the *Lueckisporites virkkiae* Interval Biozone of Souza and Marques-Toigo (2003) in the Paraná Basin contains a dated horizon of 278.4±2.2 Ma (Kungurian). Guerra-Sommer et al. (2008) reported an age of 285.4±8.6 Ma (Artinskian) within the Paraná Basin Faxinal coal seam, which is assigned to the *Hamiapollenites karooensis* Sub-biozone of the *Vittatina costabilis* Interval Biozone of Souza and Marques-Toigo (2003). Mori et al. (2012) noted a date of 281±3.4 Ma (Kungurian) for another horizon within the *Lueckisporites virkkiae* Interval Biozone of the Paraná Basin in the Candiota coal mine. Césari et al. (2011) summarised the palynostratigraphy and radiometric dating of the Carboniferous and Cisuralian sequence across Argentina and Brazil correlating the San Rafael and Paraná basin biozones and using radiometric dates to relate South American palynological biozones to those of Namibia and Australia. di Pasquo et al. (2015) gave radiometric dates from five volcanic ash beds within the Cisuralian Copacabana Formation in central Bolivia (Tarija Basin). The five dates (cited as preliminary and published only in the non-peer reviewed Permian ICS Newsletter *Permophiles*, 53, Supplement 1) are 298, 295.4–295.1 and 293 Ma (for two ash layers approximately 25 m apart stratigraphically), and 292.1–291.3 Ma. According to di Pasquo et al. (2015), these dates suggest an Asselian age for the *Vittatina costabilis* assemblage and an Asselian – Sakmarian age for the *Lueckisporites virkkiae* assemblage of di Pasquo et al. (2015).

Conclusion

This review indicates the considerable progress that has been made in palynostratigraphy since 2007 in relation to the radiometric dating of palynological biozones, mostly in the former continents of Gondwana, where ash layers have facilitated CA-IDTIMS for U-Pb dating. This has resulted in spot calibration for palynozones in several basins in South America. Perhaps the most systematic and significant progress has however been made in the Gondwana basins of Australia, in several cases moving zonal boundaries in the Permian by as much as six million years. The implications of these changes in Australia and South America are mainly still to be realised but are very likely to change our view of Permian glaciation, palaeophytogeography, and other Permian events.

To continue some of these advances, a SPS Working Group, the Euramerica-Gondwana correlation Working Group, has been set up to deal with issues such as difficulties in identifying Euramerican defined GSSPs (including the C/P boundary) in Gondwana, different provincial palynological 'taxonomies' and issues over the quality of data and information variation in different parts of Gondwana and Euramerica.

In the coming decades it is likely that radiometric dates will continue to be the most important 'glue' between palynostratigraphic schemes which reflect considerable phytogeographic provinciality, perhaps ultimately providing a basis for worldwide relatively high resolution palynostratigraphic correlation and dating.

Acknowledgement to Alex Wheeler for useful discussions.

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Permophiles 2007 – 2023: looking back and looking forward on the tasks and results of the Nonmarine-Marine Late Carboniferous – Permian – Early Triassic Correlation Working Group

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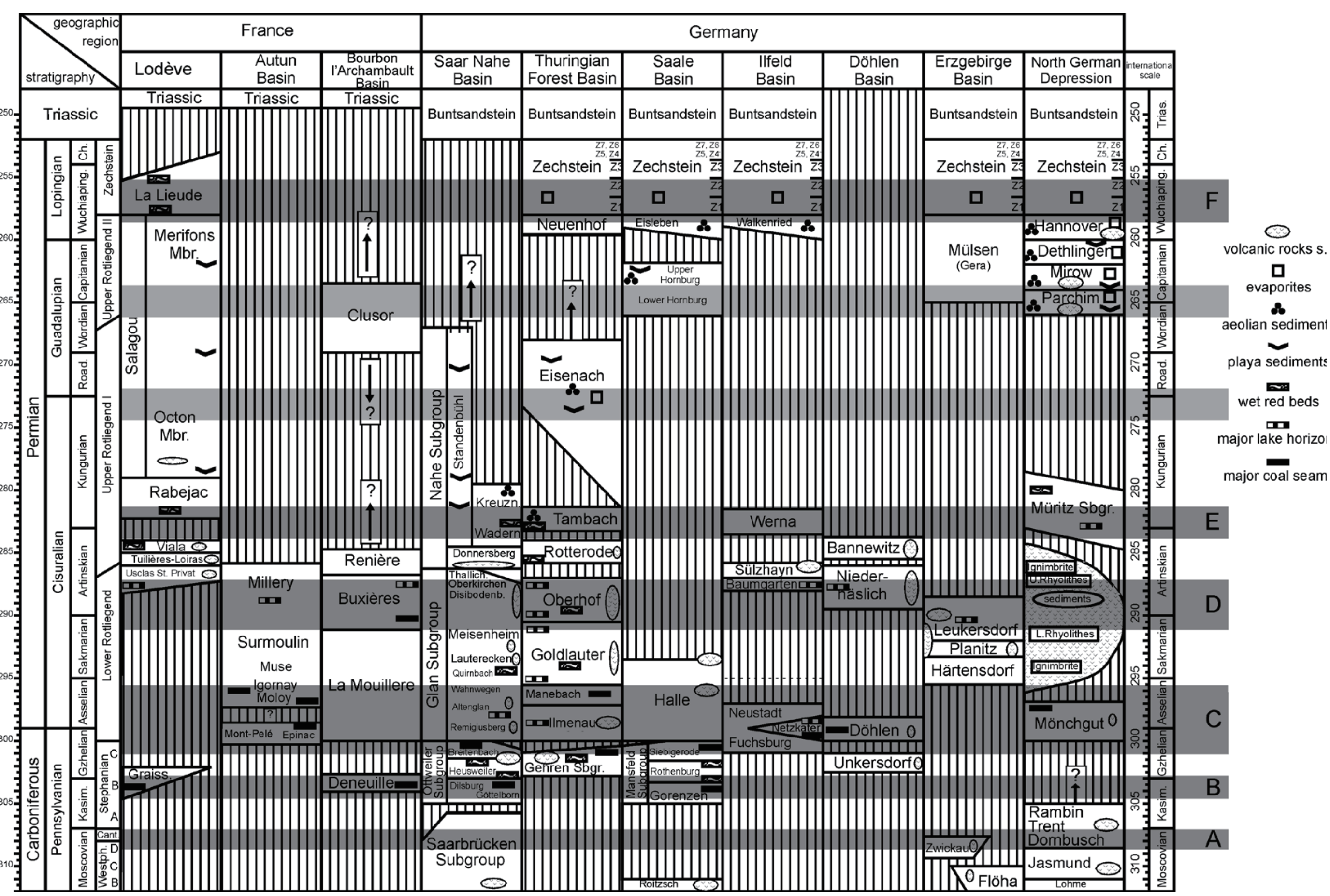
Reading *Permophiles* 50 from 2007, you will find repeated reference to the Nonmarine-Marine Correlation Working Group and the hopes placed in it to solve the problems of correlating purely terrestrial Permian deposits with the marine Standard Global Chronostratigraphic Scale. One year earlier, in 2006, Lucas, S. G., Cassinis, G. & Schneider, J. W. edited the Special Publication 265 of the Geological Society, London, on the state of the art in "Non-Marine Permian Biostratigraphy and Biochronology". There, some intercontinental correlation charts were published, for example, by Steiner, Fig. 2a, "Global magnetostratigraphic correlation of the Late and Middle Permian," including China, North America and Russia; by Lucas, Fig. 3, who correlated localities in North America, South Africa, western Europe and Russia by Land-vertebrate faunachrons (LVF); in Fig. 15a,b Roscher & Schneider (here Fig. 1a,b) showed a detailed correlation of formations from several basins in western Europe with Moroccan basins and the Karoo basin in southern Africa based on some biostratigraphy but mainly on climate stratigraphy; Lucas & Hunt demonstrated a correlation of tetrapod footprint localities in North America, Germany, France and Italy in Fig. 10; and, in Schneider & Werneburg, Fig. 3, a correlation of several European basins and the Moroccan Sous basin is demonstrated, based on fossil insect biostratigraphy. In the paper, Schneider and Werneburg (2006) wrote on p. 333 that "The conodonts and spiloblattinids of … the New Mexico occurrences could be the long-sought tools for reliable correlations of the marine Carboniferous/Permian boundary into the purely continental sections of the Euramerican Hercynides". Since then, the US-Austrian-German team of A. Lerner, L. Rinehart, D., W.A. DiMichele, K. Krainer, J.W. Schneider, S. Voigt, R.Werneburg, as well as US and German MSc- and PhD-students have focused under leadership of S.G. Lucas on excavations and fossil sampling in mixed marine-continental sections in the Upper Carboniferous and Lower Permian in the excellently exposed sections in New Mexico (Fig. 2). The focus was on the correlation of the marine Carboniferous/Permian boundary into purely continental sections of the Variscides of

Europe and North Africa by co-occurrences of marine zone-fossils, such as conodonts, with non-marine guide fossils, such as insects and tetrapod tracks, in North America. A first summary of the results was given during the "The Carboniferous-Permian Transition" meeting held in May 2013, in Albuquerque, New Mexico. In the last few years, S.G. Lucas and co-authors edited several summaries on Carboniferous, Permian, and Triassic stratigraphy in the New Mexico Museum of Natural History Bulletin, and in the Special Publications series of the Geological Society, London, most recently on "Ice Ages, Climate Dynamics and Biotic Events: the Late Pennsylvanian World", Geological Society, London, Special Publications, 535, (Lucas et al., 2023).

To trace the marine Permian-Triassic boundary into Euramerican mainly continental sections, a "Sino-German Cooperation Group on Late Palaeozoic Palaeobiology, Stratigraphy and Geochemistry" was established in 2012 with financial support of the Sino-German Center for Research Promotion. The working group was coordinated by Xiangdong Wang (Nanjing) and Hans Kerp (Muenster); participants included colleagues from the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences, and a number of German universities, including Munster University, TU Bergakademie Freiberg, University of Erlangen-Nurnberg and Munich University (Fig. 3). The results have been reported in several publications (e.g. Scholze et al., 2020) (Fig. 4) and summarized, for example in Shen et al. (2019). This cooperation continues until today – see the contribution of Shen et al. in this issue of *Permophiles*.

Cooperation in the framework of the Nonmarine – Marine Correlation Working Group with colleagues from Morocco, with M. El Wartiti and, after him, with H. Saber, dates back to the early 2000s. Since then, four PhD-students of the University of El Jadida have investigated Carboniferous, Permian and Triassic continental sediments in North Africa for fossils and their use for biostratigraphic correlations, such as insects and tetrapod tracks (e.g. Belahmira et al., 2019; Zouheir et al., 2022; Rmich et al., 2023) (Fig. 5). This was generously supported by the German Academic Exchange Survey. It was within this framework that Moroccan colleagues came up with the idea to organize special meetings for researchers of non-marine trace fossils. This became the "First International Congress on Continental Ichnology (ICCI-2015)", which was held at the Faculty of Sciences, Chouaïb Doukkali University in El Jadida, Morocco, in 2015.

Very promising are the investigations by the team of H. Kerp and B. Bomfleur of the University of Munster in cooperation with A. Abu Hamed, University of Amman, in the uppermost Permian and Lower Triassic in Jordan in the northwest of the Arabian Peninsula. Besides biostratigraphically important palynomorphs (Stephenson and Powell, 2013) and a mixed macroflora (Kerp et al., 2021; Blomenkemper et al., 2022), a number of insects have been discovered in the Upper Permian continental clastics; and volcanic ash beds will enable radioisotopic dating in the future. The Lower Triassic mixed continental and marine deposits of Jordan have delivered an interesting conchostracan fauna (Scholze



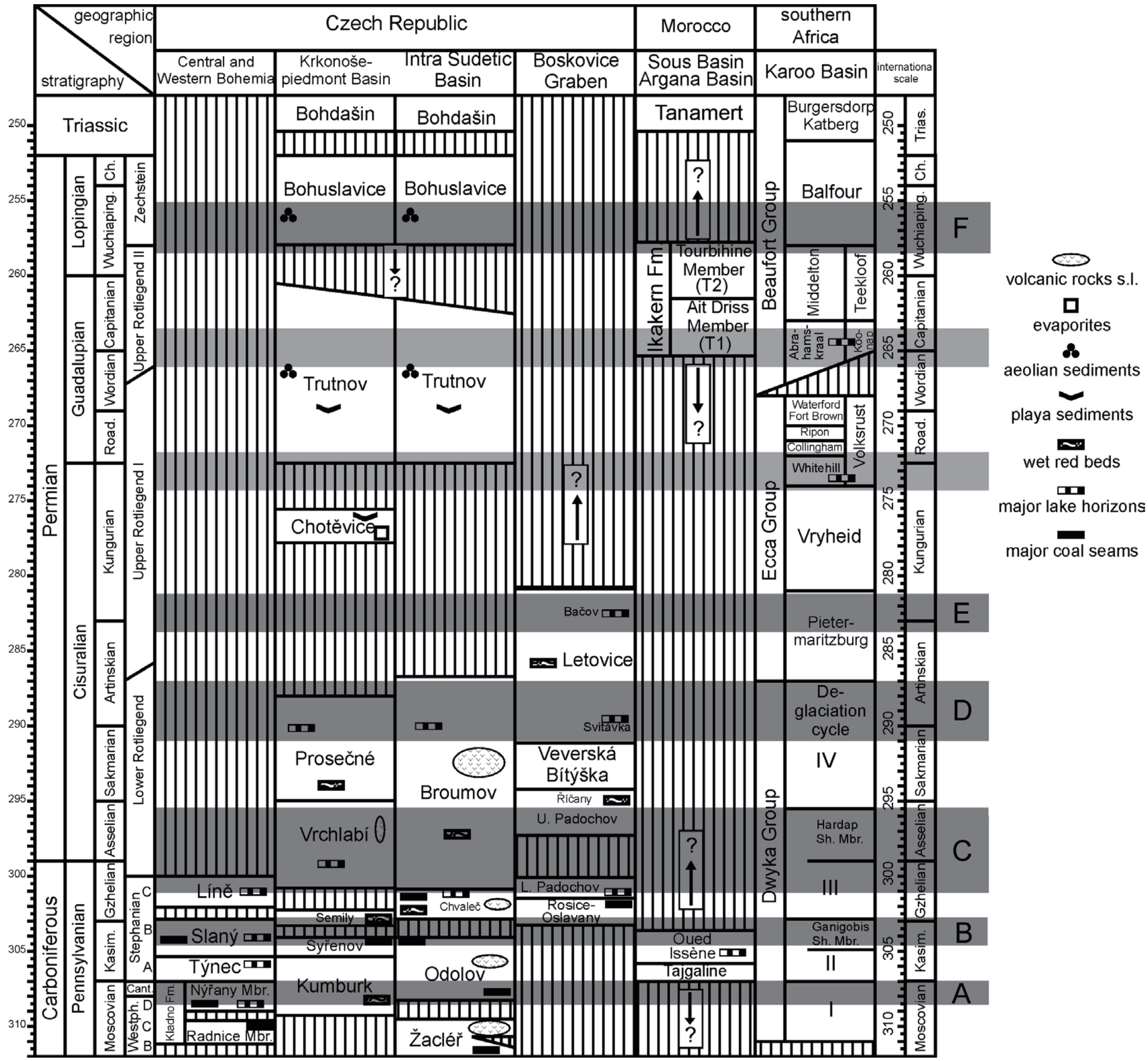


Fig. 1a, b. An early, now historical attempt for interregional correlations by Roscher and Schneider (2006), fig. 15a, b, based on sparse biostratigraphic data and on climate stratigraphy. No trustworthy data was available at that time.

et al., 2017).

Going back to the suggestion of the late V. Lozovsky, a very fruitful cooperation with Russian colleagues was initiated by V. Silantiev and his team. In the framework of a Double-MSc Programme between the Kazan University, Tatarstan, Russia, and the Technical University Bergakademie Freiberg, Germany, 12 students from Kazan University completed their MSc study in Freiberg with theses mainly dedicated to Permian biostratigraphy based on fishes and conchostracans. Results are partially published (e.g. Bakaev, 2020; Zharinova et al., 2018) (Fig. 6). Of particular importance is the joint research on Middle and Late Permian conchostracan biostratigraphy (e.g. Scholze et al., 2015, 2019) and the studies on the position of the Permian-Triassic boundary in the Kuznets Basin of Siberia, within the Angara biotic province (Davydov et al., 2021).

The Czech team, led by S. Opluštil, published in recent years very valuable data on the biostratigraphy and paleoclimatology of the Carboniferous and Permian of the Central and West Bohemian basins calibrated by numerous new high-precision radioisotopic ages (e.g. Opluštil et al., 2016a,b; Opluštil and Schneider, 2023). Similarly, important radioisotopic age data for the fixation of the C/P boundary in the classical Autun Basin and for the calibration of biostratigraphic methods in relation to the marine Standard Global Chronostratigraphic Scale are continuously produced by the French team of G. Gand et al. (e.g. Pellenard et al., 2017). Colleagues from Spain and Italy, represented in the Working Group by A. Ronchi and E. Kustatscher, provide interesting and important contributions on the Mediterranean Permian of

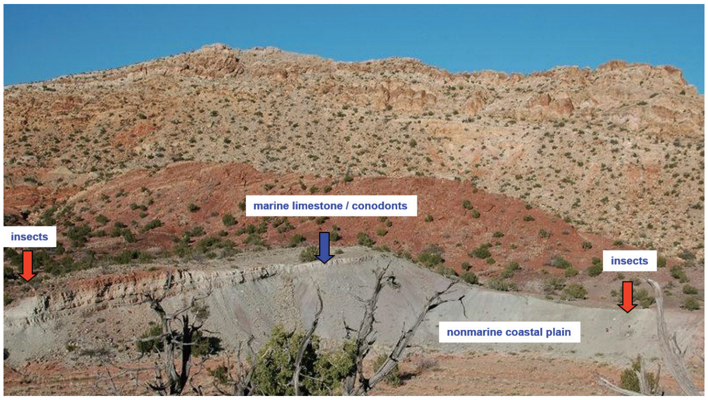


Fig. 2. Mixed marine – continental deposits with conodonts, forams, insects and conchostracans; Carrizo Arroyo, New Mexico, Red Tank Member, Bursum Formation; key section for marine-nonmarine correlation of the Pennsylvanian/Permian boundary in Euramerica.

Europe and its litho- and biostratigraphy (e.g. Ronchi et al., 2011; Kustatscher et al., 2017; Marchetti et al., 2022; Vallé et al., 2023).

The results of all these activities, listed here only as examples, have been summarized by 19 co-authors in, so far, the most comprehensive review of the stratigraphy of the continental Upper Paleozoic and Lower Mesozoic (Schneider et al., 2020). Here, Fig. 7 shows the modified Fig. 2 from this publication, which has since 2020 been continuously updated with new results. The considerable progress of the last 17 years becomes obvious when comparing this correlation table, for example, with Fig 15a,b in Schneider & Roscher (2006), here Fig. 1a,b.

However, the recent correlation chart, version August 2023, Fig. 7, also shows the problems that have not yet been solved. These are still insufficient correlations with parts of Gondwana, especially South America, India and Australia. For South America, a more intensive cooperation with the working group is emerging - in Brazil with Joao Ricetti (insect biostratigraphy) from the team of R. Iannuzzi and with P. Moisan in Chile (newly discovered tetrapod track and conchostracan localities). More critical is the mid Permian problem. Very incomplete sections of mostly fossil-pure dry red beds and missing volcanic rocks are unfortunately typical, especially for the European part of Euramerica. The Cis-Uralian basin on the East European platform has a Guadalupian section with an extensive tetrapod-fossil and conchostracan biostratigraphy but is still difficult to correlate with the Standard Global Chronostratigraphic Scale because of missing marine intercalations and datable volcanic rocks. Only the South African Karoo basin provides very good non-marine biostratigraphic records for the Middle Permian, particularly for tetrapod body fossils supported by an increasing number of radioisotopic ages provided by the team of M. Day and B. Rubidge and others (e.g. Day et al. 2022).

Compared to 2007, in 2023 the continental facies of the Permian has a relatively well-defined time frame that correlates multistratigraphically with the marine Standard Global Chronostratigraphic Scale. I would like to thank everyone, including those not mentioned here, for the good cooperation in the Nonmarine-Marine Correlation Working Group. The next big step should be done by about 2025 - the compilation of correlations of all important and regionally representative Permian basins worldwide.

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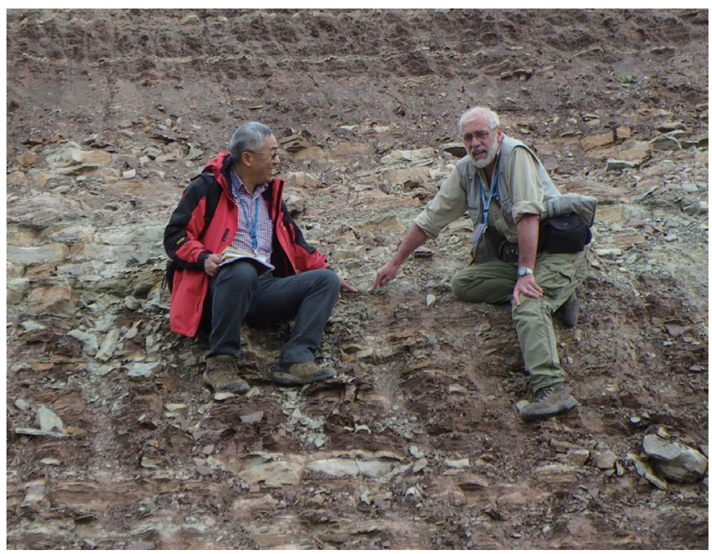

Fig. 3. Fieldwork 2013 of the Sino-German Cooperation Group on Late Palaeozoic Palaeobiology, Stratigraphy and Geochemistry in Germany. Shuzhong Shen and Joerg W. Schneider at the Permian-Triassic boundary interval in the Caaschwitz quarry in Thuringia, Central Germany.

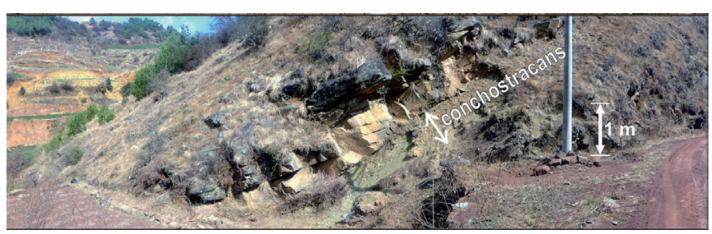

Fig. 4. Conchostracan bearing Lubei section, Jialingjiang Formation, upper Lower Triassic (Olenekian) in southwest China. From Scholze et al. (2019), Fig. 3.

Fig. 5. Outcrop situation at the Oued Issene canyon near Tanamert village, High Atlas Mts., Morocco. Exposed are plants, insects, and tetrapod track bearing deposits of the Oued Issene and Tirkou formations, Stephanian A/B, Kasimovian, overlain by the Middle to Upper Permian Ikakern Formation and the Lower Triassic Timezgadiouine Formation, both with an angular erosive unconformity at the base.

Fig. 6. Monastery Ravine section on the right bank of the Volga river south of Kazan in Tatarstan, Russia; exposed are Urzhumian (tentatively Wordian), Severodvinian (tentatively Capitanian) and Vyatkian (tentatively Wuchiapingian) continental clastics; one of the excellent and fossiliferous Middle to Upper Permian outcrops on the East European Platform.

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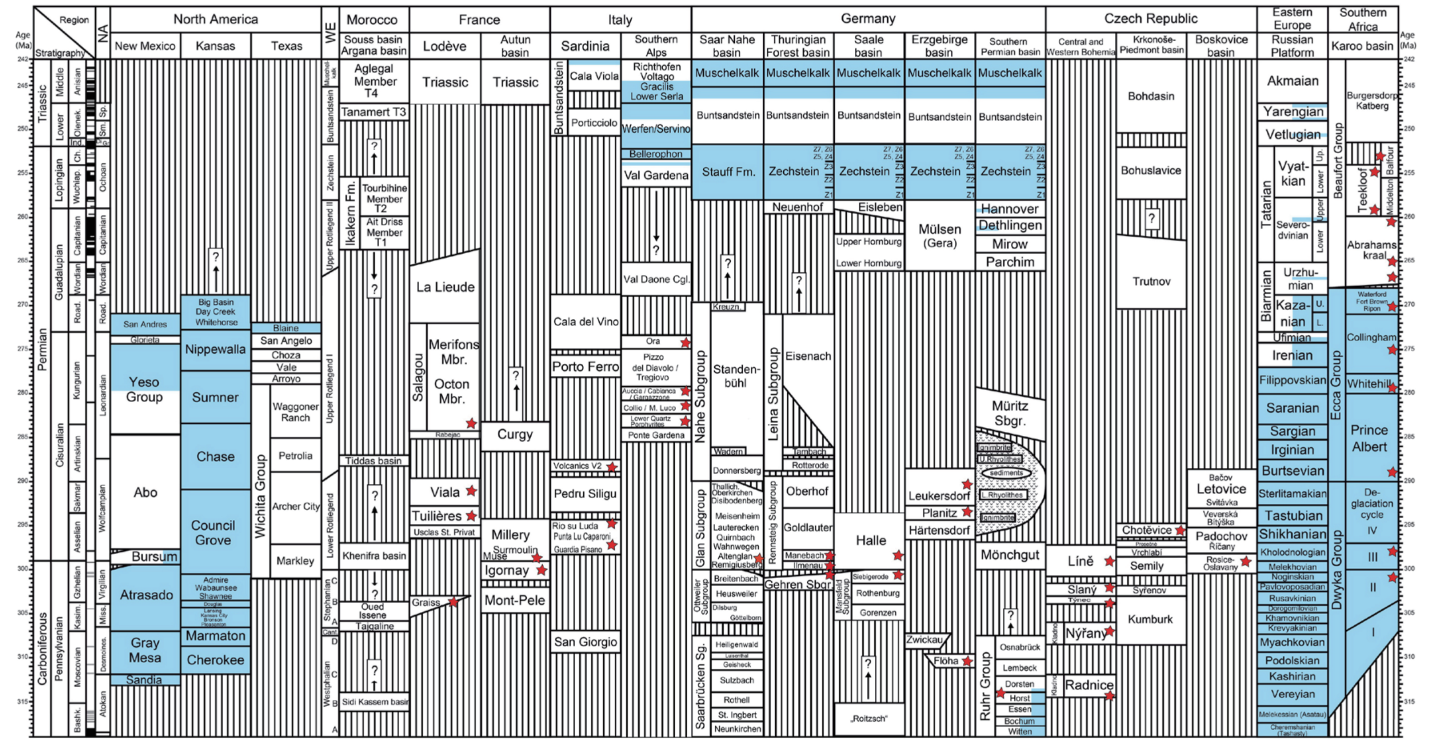

Fig. 7. Multistratigraphic interregional correlations of basins in North America, Western and Eastern Europe and Southern Africa based on biostratigraphy, magnetostratigraphy, and radioisotopic ages (red stars); updated version August 2023 of Fig. 2 in Schneider et al., (2020).

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Microfacies analysis and biostratigraphy of Lower Permian carbonate-dominated cyclothems, Robledo Mountains (New Mexico, USA) and Carnic Alps (Austria): Insights into the stepwise demise of late Paleozoic ice age (LPIA)

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Introduction

The Pennsylvanian–Early Permian marked the acme and demise of the main Phanerozoic glaciation: the Late Paleozoic ice age (LPIA). The LPIA was multi-phase with alternating glacial and interglacial intervals that stretched between the Late Devonian and the Late Permian (Rees et al. 2002; Fielding et al. 2008; Rygel et al. 2008; Lopez-Gamundi and Buatois 2010; Montañez and Poulsen 2013). One of these glacial intervals—Glacial III (Stephanian–early Sakmarian) of Isbell et al. (2003); P1 (Asselian–early Sakmarian) of Fielding et al. (2008) —was characterized by widespread ice sheets across most of Gondwana and associated glacioeustatic fluctuations formed by the waxing and waning of ice sheets (Frakes and Francis 1988; Crowley and Baum 1992; Frakes et al. 1992; Fielding et al. 2008). Contemporaneous successions in Laurussia recorded sea-level fluctuations through the accumulation of transgressive-regressive (T-R) cycles of marine and continental deposits known as parasequences or cyclothems (Dvorjanin et al. 1996; Stemmerik 2008; Fang et al. 2018). There is a debate about the amplitude of sea-level fluctuations that caused these parasequences; a wide range of amplitudes ranging from 20 to 155 m has been suggested (Joachimski et al. 2006).

In this study, microfacies analyses of two middle–upper Asselian successions of the Robledo Mountains (New Mexico) and the Carnic Alps (Austria) are used to provide an estimate of the amplitudes of sea-level fluctuations recorded in parasequences formed during the demise of the Glacial III (or P1) interval. These amplitudes are then compared to previously reported fluctuations of lower Asselian cyclothems formed at the peak of the glacial interval. Differences in amplitudes of sea-level fluctuations between lower and middle-late Asselian parasequences may indicate a gradual and stepwise, rather than sharp, demise of the main phase of the LPIA. Previously published and newly reported key small foraminifer, fusulinid and conodont taxa are used to date this shift in amplitude.

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Methods and Microfacies

A total of 336 samples from the Branson Canyon (32°21'50.00"N, 106°52'45.00"W) and Flood (32°22'11.60"N, 106°53'2.60"W) sections (Robledo Mountains, New Mexico, USA) and the Garnitzenbach (46°35'37.00"N, 13°20'50.00"E) and Zottachkopf (46°34'21.00"N, 13°13'0.00"E) sections (Carnic Alps, Austria) (Fig. 1) were grouped into microfacies based on their fabric, grain assemblage, relative proportions of clastic material and grain size following the classification by Dunham (1962). Eleven and thirteen microfacies were identified in samples from the Robledo Mountains and Carnic Alps, respectively (Calvo González et al. 2023). Conodont samples were collected in the Branson Canyon and Flood sections and processed following standard processing techniques at the University of Calgary. Conodont elements were hand-picked and photographed with a scanning electron microscope.

Geological Setting

The Branson Canyon and Flood sections are located in the Prehistoric Trackways National Monument (PTNM) on the southeastern part of the Robledo Mountains (Fig. 1). They include the upper part of the Community Pit, Robledo Mountains and lower part of the Apache Dam formations (Fig. 2). The Robledo Mountains are one of the many lateral fault blocks associated to the Rio Grande rift system of the Basin and Range Province and comprise Ordovician–Lower Permian rocks (Lucas et al. 2015). Pennsylvanian–Lower Permian strata in these mountains are composed of cyclic to non-cyclic carbonate-dominated rocks of the Horquilla, Shalem Colony, Community Pit, Robledo Mountains and Apache Dam formations. In this study, the upper 103.9 m of the Community Pit Formation was measured at the Flood section and comprise bedded limestone, shale interbeds and common covered intervals. The whole Robledo Mountains Formation was measured at the Branson Canyon section and comprise bedded limestone, sandstone, siltstone, shale and covered intervals. Lastly, the lower part of the Apache Dam Formation was measured at the Branson Canyon section and comprise bedded locally cherty limestone and shale interbeds.

The Garnitzenbach and Zottachkopf sections are located along the Garnitzenklamm gorge and the northern wall of the Trogkofel massif in the Carnic Alps, respectively (Fig. 1). These sections include the Zweikofel, Zottachkopf and lowermost part of the Trogkofel formations (Fig. 2). The Carnic Alps are part of the Central European Variscides which in turn are part of the Variscan Belt, which resulted from the collision between Gondwana and Laurussia (Franke 1989). In the study area, Devonian–Carboniferous rocks make up the Variscan basement. These strata are followed by Pennsylvanian–Permian post-Variscan sediments deposited in successor basins following the Variscan Orogeny (Läufer et al. 2001). These sediments are composed of cyclic to non-cyclic carbonate-dominated rocks of the Bombaso Formation and the Auernig, Rattendorf and Trogkofel groups and the Tarvis Breccia (Krainer et al. 2019). The uppermost part of the Grenzland, Zweikofel, Zottachkopf and lowermost part of the Trogkofel formations of the Rattendorf and Trogkofel groups were sampled. The uppermost 17 m of the Grenzland, the whole Zweikofel and the basal 2 m of the Trogkofel formations were measured at the Garnitzenbach section. This section comprises well-bedded and cyclic sediments overlain by the non-cyclic, massive strata of the Trogkofel Formation. The whole Zottachkopf and basal 3 m of the Trogkofel formations were measured at the Zottachkopf section and they comprise well-bedded, non-cyclic strata of the Zottachkopf Formation overlain by the massive limestone of the Trogkofel Formation.

Discussion

Biostratigraphy

Robledo Mountains

Small foraminifers (Lucas et al., 2015), previously reported conodonts (Kozur and LeMone, 1995) and newly-collected conodont specimens are used to reinterpret the age of the studied interval in the Robledo Mountains. The Horquilla-Shalem Colony contact is interpreted as lowermost Asselian based on the occurrences of *Streptognathodus longus*, *S. grandis*, *S. paraisolatus* and possibly *S. wabaunsensis* in the uppermost interval of the Horquilla Formation that indicating correlation with the Streptognathodus glenisteri Zone (Henderson 2018) in the uppermost interval of the Horquilla Formation. These taxa were reinterpreted from reported occurrences of *S. conjunctus* and *S. binodosus* in Krainer et al. (2015). In the Shalem Colony Formation, *S. longus*, *S. invaginatus*, *S. expansus* and the small foraminifers *Geinitzina postcarbonica*, *Climacammina* sp. and *Tezaquina clivuli* are used to interpret this formation as lower Asselian (Groves and Wahlman, 1997; Pinard and Mamet, 1998; Groves and Boardman, 1999; Pan and Erwin, 2002; Beauchamp et al., 2022a). Overlying this formation, the middle part of the Community Pit Formation in the Flood section yielded a fauna including *Sweetognathus expansus*, *Sw. merrilli* and an unknown taxon labelled *Sweetognathus* sp. A that share similarities with occurrences of *Homeoiranognathus huecoensis* in the Franklin Mountains and *Xuzhougnathus monoridgosus* in North China. The fauna is therefore interpreted as Asselian (Ritter, 1986; Gao et al., 2005) (Fig. 3). The occurrence of this unknown taxon in the Community Pit may suggest a high degree of sweetognathid morphologic plasticity in the Asselian (Read and Nestell, 2018). In the Robledo Mountains Formation, various limestone strata yielded elements of *Sw. posterus*, *Sw. posterus* transitional to *Sw. binodosus*, *Sw. sulcatus* and a broken element of *Mesogondolella* (Fig. 3). Kozur and LeMone (1995) reported *Sw. primus* and *Sw. merrilli* posterus from the same interval in the middle part of the formation. However, based on the re-examination of their illustrated specimens, *Sw. merrilli posterus* is herein interpreted as *Sw. posterus* following the practice in Beauchamp et al. (2022b). Occurrences of *Sw. posterus* in the Robledo Mountains Formation resemble some specimens identified by Ritter (1986) in the Cerro Alto Formation as *Sw. inornatus*. Small foraminifers including *Amphorateca* sp., also retrieved in the Crouse cyclothem of Kansas and Asselian strata of the Canadian Arctic and Norway, confirm the Asselian affinity of the lower half of the formation (Groves and Wahlman 1997; Pinard and Mamet 1998; Groves and Boardman 1999; Lucas et al. 2015). The upper half of the Robledo Mountains and most of the Apache Dam formations are interpreted as Sakmarian based on the occurrence of *Sweetognathus* cf. *anceps*, two juvenile specimens of *Diplognathodus stevensi* and *Sweetognathus* sp. in the Apache Dam Formation (Fig. 3). These occurrences are indicative of a Sakmarian/late Sakmarian age.

Carnic Alps

Small foraminifer taxa and previously reported conodonts are used to reinterpret the age of the studied succession in the

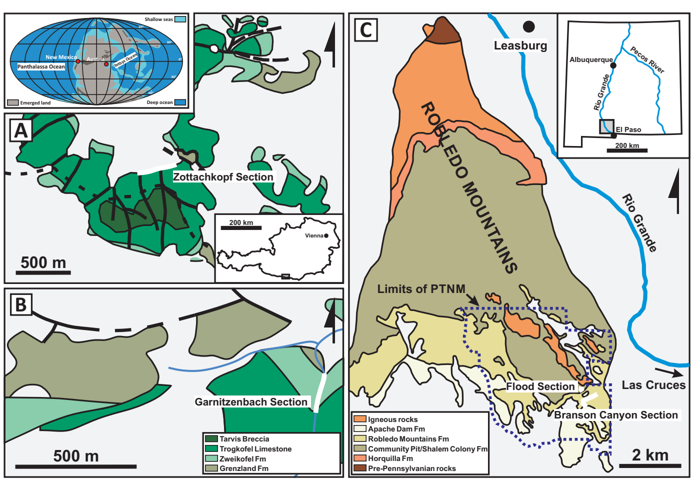

Fig. 1. Geological maps showing locations of measured sections. A. The composite Zottachkopf section was measured along the northern side of the Trogkofel massif, immediately north of the Austria-Italy border; B. The Garnitzenbach section was measured along the Garnitzenklamm gorge; C. The Branson Canyon and Flood sections were measured on the southeastern part of the Robledo Mountains within the Prehistoric Trackway National Monument (PTNM).

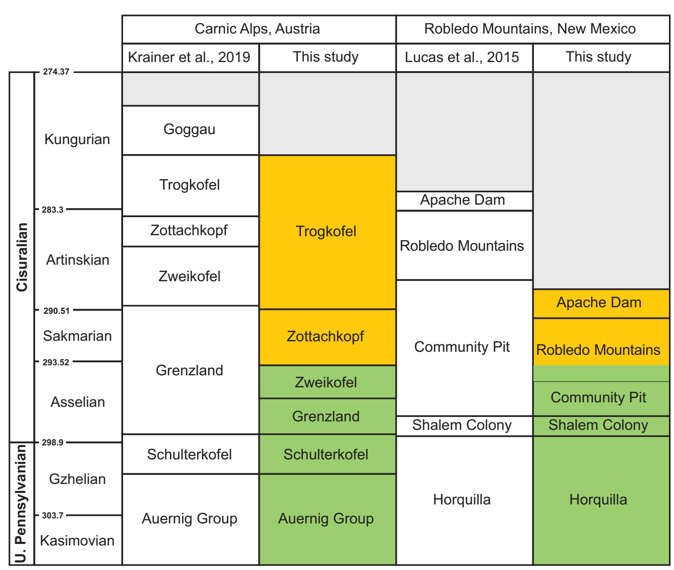

Fig. 2. Table showing the studied stratigraphy, its previous age interpretation by Krainer et al. (2019) and Lucas et al. (2015) and the age interpretation provided in Calvo González et al. (2023) labelled as “this study”.

Carnic Alps. Below the interval of interest, the Schulterkofel Formation was interpreted as Pennsylvanian-Permian based on the occurrences of *Ultradaixina dashtidzhumica*, *Ul. postgalloway*, *Schellwienia ulukensis* and *Ruzhenzevites parasolidus* (i.e., typical Gzhelian fauna in the Tethys) followed by *Rugosofusulina*, *Schellwienia bornemani*, *Likharevites* cf. *inglorious* and *Schwagerina versabile* (i.e., characteristic of the lowermost Permian) by Davydov et al. (2013). In the interval of interest, previous age determinations were mainly based on fusulinid and small foraminifer taxa due to the scarcity of conodonts. The same conodont element was illustrated by Forke (2002) in the uppermost part of the Grenzland Formation and by Davydov et al. (2013) in the lower part of the Zweikofel Formation. It was interpreted as *Sweetognathus* aff. *whitei* by Forke (2002) and as *Sweetognathus anceps* by Davydov et al. (2013). In this study, this element is reinterpreted as *Sweetognathus binodosus* transitional to *Sw. anceps* based on its prominent, dumbbell-shaped nodes, narrow grooves and lack of an axial ridge. Forke (1995) recognized *Sweetognathus* aff. *whitei*, *Sweetognathus inornatus*, *Neogondolella* cf. *bisselli* (now *Mesogondolella*), *Sweetognathus* sp. and *Diplognathodus expansus* in the overlying Zottachkopf and Trogkofel formations in the Trogkar section. However, in this study *Sweetognathus* aff. *whitei*, *Sweetognathus inornatus* and *Diplognathodus expansus* are reinterpreted as *Sweetognathus anceps*, *Sweetognathus binodosus* and *Sweetognathus expansus*, respectively. The lower part of the Trogkofel Formation yielded a juvenile form of *Neostreptognathodus* cf. *pequopensis* at the Zweikofel massif (Forke 2002), but this form is a homeomorph (see Read and Nestell, 2018). Based on these conodont taxa, the Zweikofel and lowermost part of the Zottachkopf formations are herein interpreted as Asselian and the rest of the Zottachkopf Formation as Sakmarian. The presence of several specimens of *Boultonia willsi* in the lower interval of the Zottachkopf Formation in this study may be used to confirm a late Asselian-Sakmarian affinity of these rocks (Fig. 4). Occurrences of *B. willsi* were also reported in a similar interval of the Zottachkopf Formation at locality Höhe 2004 and in the upper interval of the type section of the Zweikofel Formation (Forke 2002; Davydov et al. 2013). *Biwaella omiensis*, *Cribrogenerina gigas*, *Amphorateca* sp. and *Tezaquina* cf. *clivuli* were also recovered in this stratigraphic interval and can be used to further support our age determination due to occurrences of these taxa in Asselian rocks of the Canadian Arctic, United States and South China (Davydov et al, 2013; Krainer et al. 2019; Read and Nestell 2019; Beauchamp et al. 2022a).

Amplitudes of glacioeustatic fluctuations

Robledo Mountains

Microfacies analysis of the cyclic Horquilla Formation was carried out by Krainer et al. (2015; 2017) in the Robledo and Big Hatchet mountains. Based on Flügel's (2004) standard microfacies types (SMF) utilized in Krainer et al. (2015), the authors concluded that glacioeustatic amplitudes in these cyclothems were on the range of tens of metres. However, based on the microfacies illustrated in their study, occurrences of rhizolith and microkarst horizons and interbeds of poorly sorted conglomerates, there is room for reinterpretation of the amplitudes recorded in these cyclothems. Similarly, microfacies illustrated in Krainer et al. (2017) in the Big Hatchet Mountains and the presence of several subaerial exposure surfaces can be used as evidence for higher-amplitude glacioeustatic fluctuations at this location. Photomicrographs in Krainer et al. (2015) illustrate four fossil assemblages that are typically deposited at different depths: Heterozoan (i.e., echinoderms, bryozoans, brachiopods, ostracods and foraminifers in a wackestone matrix), Photozoan-extended (i.e., rare fusulinids, echinoderms, bryozoans and phylloid algae), Photozoan (i.e., ooids, oncoids, fusulinids and calcareous algae) and Hyalosponge (i.e., siliceous sponge spicules) associations. This suite of fossil assemblages suggest depositional environments spanning the entire platform from very shallow, high-energy settings above fair-weather wave base (FWWB) and the thermocline (i.e., a few metres deep) to relatively deep, moderate-energy settings above or below storm-weather wave base (SWWB) and below the thermocline (i.e., up to 80-100 metres deep). Photomicrographs in Krainer et al. (2017) illustrate a similar microfacies suite that further supports high-amplitude glacioeustatic fluctuations in the Horquilla Formation. Root structures, in situ brecciation and mud cracks on subaerial exposure surfaces throughout the formation attest to large scale sea-level drops during the regressive systems tract at the end of each cycle (Krainer et al., 2015, 2017).

In the Shalem Colony Formation, Lucas et al. (2015) also categorized microfacies into SMFs. According to these authors, these microfacies represented sedimentation on an inner to mid-ramp environment. Calcrete horizons and rhizoliths throughout the formation suggest episodes of subaerial exposure. Importantly, these covered and shale units alternating with limestone beds were interpreted by Lucas et al. (2015) as offshore deposits. Thus, amplitude of glacioeustatic fluctuations in the Shalem Colony Formation may have been on the order of 100 m, similar to the Horquilla Formation.

In this study, the upper part of the Community Pit and the whole Robledo Mountains formations were studied and divided into microfacies (Calvo González et al., 2023). In the Community Pit Formation, interpreted depositional environments range between intertidal to shallow subtidal settings. Intertidal and restricted subtidal facies are composed of unfossiliferous to poorly-fossiliferous mudstone and wackestone with peloids, ostracods, sponge spicules and gastropods. Shallow subtidal facies are composed of slightly more diversified wackestone and packstone with sponge spicules, peloids, encrusting and small foraminifers, ooids, calcareous algae, ostracods and bivalves. These microfacies are interpreted to represent glacioeustatic fluctuations with amplitudes of a few tens of metres. Subtidal microfacies were likely deposited under low- to moderate-energy conditions in a shallow environment above the thermocline and FWWB. Deeper water microfacies in the Community Pit Formation were not observed. In the lower two thirds of the Robledo Mountains Formation, microfacies are similarly indicative of intertidal to shallow subtidal environments. Intertidal facies are composed of red-coloured sandstone, siltstone and shale. Subtidal microfacies comprise wackestone, packstone and grainstone with peloids, ostracods, encrusting

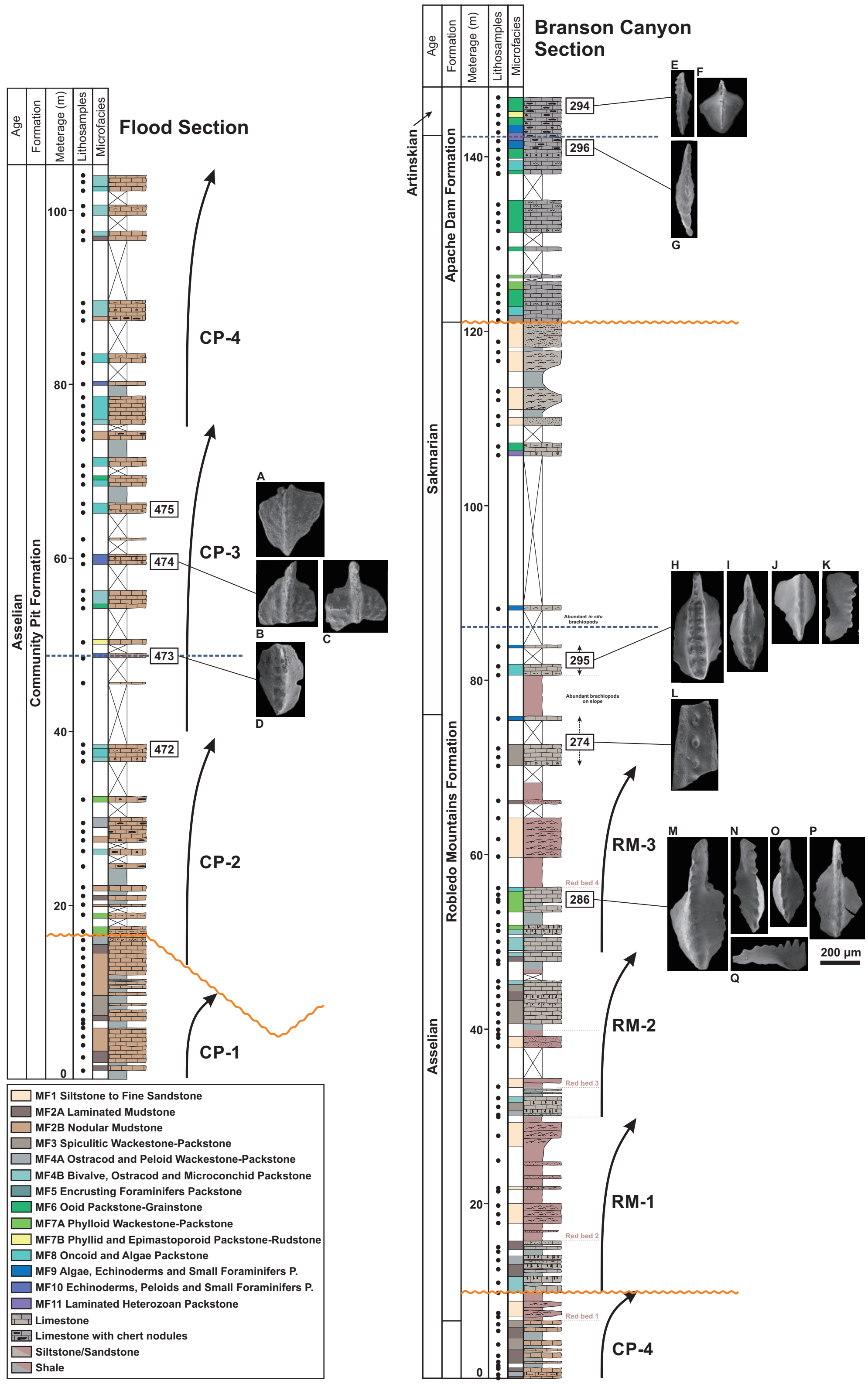

Fig. 3. Flood and Branson Canyon stratigraphic sections showing observed cyclothems (i.e., CP1–CP4 in the Community Pit Formation and RM1–RM3 in the Robledo Mountains Formation) and microfacies. SEM photographs of retrieved conodont specimens indicate the occurrence of elements in sections. Orange wavy line: low-order sequence boundary; Dark blue dashed line: low-order maximum flooding surface. A-C. *Sweetognathus* sp. A, sample 474, 60 m; D. *Sweetognathus merrilli*, sample 473, 48.6 m; E. *Sweetognathus* sp., sample 294, 146.7 m; F. *Diplognathodus stevensi*, sample 294, 146.7 m; G. *Sweetognathus* cf. *anceps*, sample 296, 140.7 m; H. *Sweetognathus sulcatus*, sample 295, ~ 81.6–85 m; I. *Sweetognathus posterus* transitional to *Sw. binodosus*, sample 295, ~ 81.6–85 m; J-K. *Sweetognathus posterus*, sample 295, ~ 81.6–85 m; L. *Mesogondolella* sp., sample 274, ~ 70–75 m interval; M-Q. *Sweetognathus posterus*, sample 286, 55.4 m. 200 µm scale bar applies to all illustrated conodonts.

and small foraminifers, bivalves, gastropods, calcareous algae, fusulinids, bryozoans and oncoids. The presence of allochems like fusulinids, bryozoans, oncoids and echinoderms in these rocks may suggest a more open-marine affinity than observed in Community Pit strata. Subtidal facies in the Robledo Mountains Formation likely formed in shallow water above the thermocline, between FWWB and immediately below SWWB. Similar to the Community Pit cyclothems, we suggest that amplitudes recorded in the Robledo Mountains Formation are on the order of tens of metres.

Carnic Alps

The Pennsylvanian Schulterkofel Formation is composed of massive algal mounds and well-bedded intermound facies (Samankassou, 1999). Mound facies are characterized by boundstone with algae *Anthracoporella*, *Epimastopora*, fusulinids and small foraminifers, whereas intermound facies comprise phylloid and dasyclad algae, encrusting foraminifers, echinoderms, bryozoans, fusulinids, Tubiphytes and gastropods (Krainer et al., 2003). Both facies were interpreted by Samankassou (1999) as shallow water facies deposited below FWWB and above the thermocline. Wackestone and packstone units with brachiopods, trilobites and sponge spicules blanket both mound and intermound facies. These facies were interpreted to result from rapid eustatic sea-level rise that drowned the algal mounds in a deep-water environment below the thermocline, likely on the mid- to outer-ramp (Samankassou, 1999).

In this study, the overlying Zweikofel, Zottachkopf and lowermost part of the Trogkofel formations were studied and divided into microfacies (Calvo González et al., 2023). Only the Zweikofel Formation comprises cyclothems. Interpreted depositional environments from Zweikofel microfacies range between an open-marine, mixed carbonate-siliciclastic inner ramp environment above FWWB and a mid-ramp above the thermocline and immediately below FWWB. Facies interpreted as inner ramp deposits comprise wackestone, packstone and grainstone with a highly diversified grain assemblage of calcareous green and red algae, oncoids, ooids, fusulinids, small foraminifers and ostracods. Facies interpreted as mid-ramp deposits include wackestone, packstone and grainstone with a similarly highly diversified grain assemblage. Based on the relative similarity between inner and mid-ramp facies associations observed in the Zweikofel Formation, the authors interpreted glacioeustatic sea-level amplitudes of a few tens of metres. No cyclothems were observed in the Zottachkopf or Trogkofel formations.

The contrast in the amplitude of glacioeustatic fluctuations interpreted from cyclothems in the studied sections may imply a gradual decrease in the amount of water contained in Gondwanan ice sheets during the Glacial III/P1 interval. High glacioeustatic amplitudes in Upper Pennsylvanian–lower Asselian cyclothems of the Horquilla, Shalem Colony and Schulterkofel formations were likely related to Milankovitch-driven sea-level fluctuations compounded by the effect of waxing and waning of widespread ice sheets. Conversely, middle–upper Asselian cyclothems of the Community Pit, Robledo Mountains and Zweikofel formations record glacioeustatic amplitudes of a few tens of metres. This lower amplitude may be linked to the decline in the volume of Gondwanan ice sheets during the demise of the glacial phase. The absence of glacioeustatic fluctuations in younger Apache Dam, Zottachkopf and Trogkofel formations may indicate the absence of widespread ice sheets postdating the Asselian–Sakmarian boundary.

Conclusions

Reinterpreted fluctuations of early Asselian cyclothems in the Robledo Mountains and Carnic Alps provide evidence for glacioeustatic fluctuations close to 100 m. This amplitude contrasts with the fluctuations of a few tens of metres interpreted in middle-late Asselian cyclothems at the same localities using microfacies analysis. Sakmarian and younger strata in the studied areas display no obvious glacioeustatic sea-level fluctuations. The progressive reduction in the amplitude of glacioeustatic fluctuations during the Asselian mirrors the acme and subsequent demise of the main phase of the LPIA (Glacial III/P1 interval). Additionally, it may indicate a stepwise and gradual decline in the volume of water that was tied up in Gondwanan icesheets during the middle-late Asselian following peak glaciation in the early Asselian.

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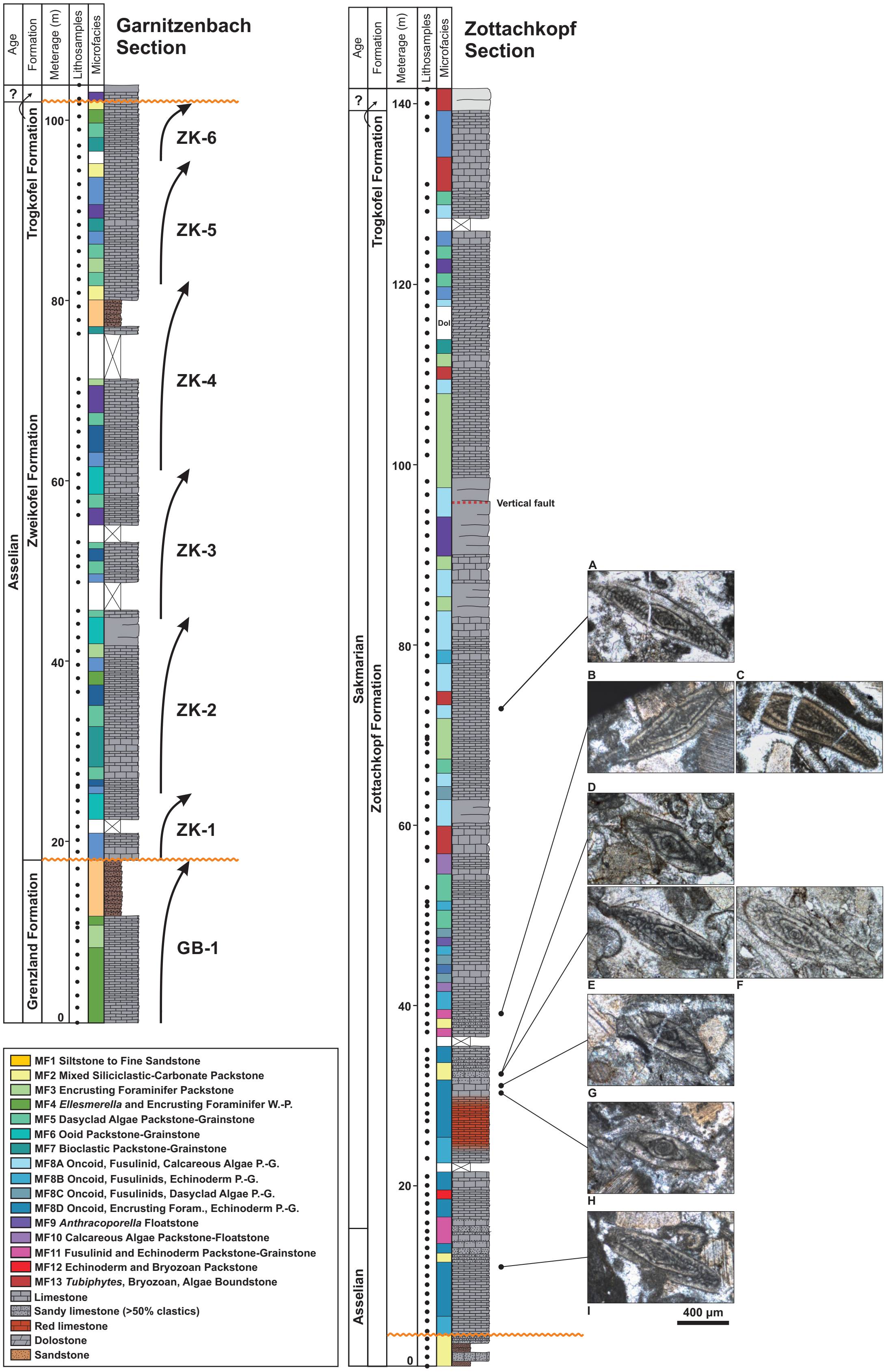

Fig. 4. Garnitzenbach and Zottachkopf stratigraphic sections showing observed cyclothems (i.e., GB1 in the Grenzland Formation and ZK1–ZK6 in the Zweikofel Formation) and microfacies. Photomicrographs of biostratigraphically relevant foraminifers indicate their location in the Zottachkopf section. Orange wavy line: low-order sequence boundary. *Boultonia willsi*: A, B, C, E, F and I; *Schubertella kingi* (?): D, G and H. 400 µm scale bar applies to all illustrated foraminifers.

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USPS Project Report: An exceptional Middle to Upper Permian tetrapod track fauna of Pangean Euramerica (Hornburg Formation, Germany)

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Every geologic succession is different and reveals its own challenges regarding environment interpretation and stratigraphic position. Some stratigraphic intervals don't yield body fossils, which may hamper the research progress on stratigraphic correlations of strata between different sites. Trace fossils of, e.g., Permian tetrapods are much more common than their skeletal remains and at the same time they reveal taxonomic information about their trackmakers. This knowledge can be used for detailed biostratigraphy. The Middle to Upper Permian Hornburg Formation (Fm.) of central Germany (see *Permophiles* no. 72) unveils a complete fan- and playa-system and its biota, which is rarely preserved in central Europe. The high trace fossil content of these dry evaporitic red beds is exceptional on a worldwide scale. The Permian Wolferode quarry site (Eisleben municipality, Saxony-Anhalt) exposes a succession of fossiliferous laminated claystones with alternating sand and siltstone beds. The sediments belong to the uppermost strata of the Hornburg Fm., which were deposited in playa lakes and ponds around 260 to 266 million years ago.

Dr Michael Buchwitz (Museum für Naturkunde Magdeburg, Germany) and I (University College Cork, Ireland) were excavation leaders for a joint palaeontological excavation campaign of the Museum für Naturkunde Magdeburg, the Technical University Bergakademie Freiberg, the State Office of Geology and Mining Saxony-Anhalt (all Germany) and the University College Cork (Ireland). Along with colleagues from Germany, Italy, Ireland and UK, we excavated, documented and described vertebrate and invertebrate trace fossils of the Wolferode site.

Fieldwork in Wolferode took place from September 10th to October 1st, 2022 and started with the removal of almost two metres topsoil of an area of about 60 m^2 close to the quarry edge with a rental excavator. In the following weeks, we focused on an area of ca. 25 m^2 and dug manually down (surface = youngest sediments) into increasingly older sediments. We excavated sediment layer by layer (mm to cm scale) with shovels, pickaxes, crowbars, hammers, chisels, and screwdrivers. Every layer was cleaned with brushes and investigated for lithology, sediment patterns and fossil content. Before recovery of track bearing surfaces, trackway sketches on foil were prepared. Some specimens required in situ preparation with glue. The recovered fossils were wrapped and labelled for the preparation lab. In total, we filled 40 crates with specimens, which are stored in the Museum für Naturkunde Magdeburg.

Fossils include insect body imprints, insect trackways, tetrapod imprints and jellyfish imprints (usually on claystone, Fig. 1). There are at least two different tetrapod imprint morphologies and abundant insect trackway morphologies. Insect body imprints are rare with different morphologies but show clear imprints of six legs and segmented bodies. Jellyfish imprints are rare and typically show a circle of a few millimetres in diameter enclosing a central cross or star. Jellyfish are more abundant in the lower part of the profile (which is not entirely exposed yet). In general, the preservation quality seemed to increase following the geological profile downwards (from younger rocks to older rocks).

In the following months we will interpret the findings in terms of biostratigraphy, tracemaker behaviour and palaeoenvironment. We will also use photogrammetry to create 3D models of

Fig. 1. The excavation in the Permian Wolferode quarry site (Saxony-Anhalt, Germany). A, D. Exposure, cleaning and documentation of invertebrate and vertebrate track bearing surfaces; B. Some sandstone beds revealed desiccation crack casts, load casts and/or ice crystal casts on the underside; C. Several tetrapod tracks (convex hyporelief) on one specimen; E. Insect body imprint, undetermined, in claystone. Producer may be a larval dragonfly; F. Insect trackway (arrows) in claystone. Photos by Anna Schöneberger (A), Daniel Falk (B, F, E), Valerio Granata (D) and Michael Buchwitz (C).

individual tracks and surfaces. Due to the high density of fossil contents, the high preservation quality and the scientific importance of the site the excavation will be continued in September 2023. We are currently looking for funding partners and volunteers.

The excavation in 2022 was a huge scientific success and generated a wide media coverage (e.g., TV, newspapers, online). My functions included being project organizer, excavation leader and correspondent person for media/public outreach. Those experiences enhanced my professional development skills and enriched my scientific networks.

I am grateful for the SPS Research Fund. Many thanks to the SPS for offering the grant to me. The grant money was used for accommodation costs, the photogrammetry software Metashape and to reduce living costs of excavation volunteers. Special thanks to the excavation team members Alice Pieri, Anna Schöneberger, Birgit Gaitzsch, Dan Cirtina, Francesco Nobile, Jörg Schneider, Jürgen Waschkuhn, Michael Buchwitz, Roland Möhring and Valerio Granata and those that are not mentioned here. I also want to thank Maria McNamara, the European Association of Vertebrate Palaeontologists, and the Irish Research Council.

Tracking the end-Permian event through a magma minefield: the Tasmania Basin, Australia

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At first glance, the Late Permian climate and vegetation of Tasmania, Australia, wouldn't have seemed so different to today. However, 252 million years ago, Tasmania would have been well within the south polar circle (Fig. 1). Despite this latitude and the attendant winter darkness, the moist temperate climate promoted a vast ecosystem at the south polar end of Pangaea. On land, dense, peat-forming forests comprised the Glossopteris Biome (McLoughlin, 2011), while the lake and river ecosystems were inhabited by their freshwater algal counterparts: the Peltacystia Province (Mays et al., 2021a). The spread of the *Glossopteris* biome was not only vast in space, but persistent in time, thriving for tens of millions of years, even through a series of major cooling events. As such, it may have been one of the most enduring in Earth's history. It was not until the worst of all mass extinctions that this biome finally collapsed.

The BIG one

The end-Permian event (EPE; ~252 million years ago) has been linked to rapid, planet-scale warming (Sun et al., 2012; Frank et al., 2021). The Australian stratigraphic record offers a globally unique opportunity to explore the severity and pace of continental ecosystem collapse in response to this hyperthermal event across a broad latitudinal range. The Bowen, Sydney and Tasmania basins of eastern Australia collectively represent a ~2500 km north-south transect (Fig. 1) of contemporaneous continental floras and depositional environments during the Late Permian and Early Triassic (palaeolatitudes: ~45–75°S; Muttoni et al., 2009). From the Sydney Basin, a timeline of continental environmental and floral changes in the region has been constructed (Fielding et al., 2019, 2021; Mays et al., 2020, 2021b; Vajda et al., 2020; McLoughlin et al., 2021). More recently, this timeline has been successfully applied to the Bowen Basin (Frank et al., 2021; Fielding et al., 2022). During the Permian–Triassic, the poorly studied Tasmania Basin was situated within the south polar circle (ca 75°; Fig. 1A). Thus, it is the highest palaeolatitude basin of Australia, providing a window into polar ecosystem responses during the EPE, and the

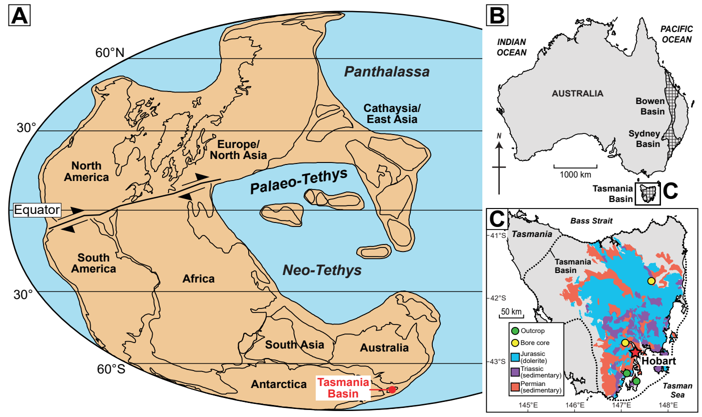

Fig. 1. Geographic and geologic contexts for this study. A. Paleogeographic map, ~latest Permian (adapted from Muttoni et al., 2009). B. Eastern Australian basins with Permian and/or Triassic strata mentioned in this study. C. Geological map of the Tasmania Basin (from Brown et al., 2021) with target successions and approximate distributions of Permian-Triassic sedimentary strata and Lower Jurassic dolerites.

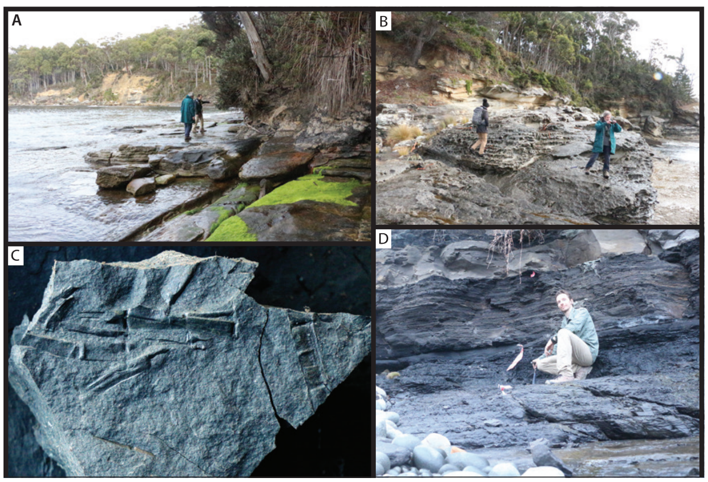

Fig. 2. Uppermost Permian outcrops and fossils, Adventure Bay, Bruny Island, Tasmania. A, B. Examining and identifying mudrock overbank deposits within the fluvial sandstone-dominated outcrops of the Cygnet Coal Measures. C. The most common macrofossil remains from these outcrops are Vertebraria, the root taxon of the *Glossopteris* plant. D. An exceptional outcrop of the uppermost Permian coal bed of the Tasmania Basin, overlain by mudrock-dominated heterolithic facies.

most direct chronostratigraphic and biogeographic links between Antarctica and eastern Australia.

Our team has collected a combination of palynological, geochemical, macrofloral and sedimentological datasets from the Tasmania Basin to: 1, constrain the chronostratigraphy of the uppermost Permian and Lower Triassic of the Tasmania Basin; 2, explore the polar ecosystem responses to the extreme EPE climate; and 3, facilitate further correlations of uppermost Permian and Lower Triassic strata between localities across greater Gondwana (e.g., Antarctica, India, southern Africa).

Tasmania's 'dead zone'

The Tasmania Basin covers most of the island of Tasmania, SE Australia (Fig. 1). Strata of this age form part of the Upper Parmeener Supergroup and were deposited in predominantly non-marine (fluvial and minor lacustrine) conditions on broad alluvial or coastal plains (Reid et al., 2014). Within this supergroup, the Permian-Triassic boundary had been identified at or near the contact between the Cygnet Coal Measures and the overlying Ross Sandstone (or their stratigraphic equivalents; Reid et al., 2014). In eastern Australia, the continental expression of the EPE precedes the P-T boundary by up to ~300,000 years at mid- to high southern palaeolatitudes (Fielding et al., 2019, 2021); hence, the upper Cygnet Coal Measures were targeted for evidence of the initial stages of the end-Permian extinction interval.

The search started with an examination of Cygnet Coal Measures and Ross Sandstone outcrops along the southern coast of Tasmania. The coal-bearing strata at Adventure Bay yielded fossil evidence typical of the pre-EPE Permian: charcoal-rich peats, and palaeosols riddled with Glossopteris leaves along with the glossopterid root taxon, Vertebraria (Fig. 2). Of particular interest was an outcrop that included organic-rich mudrocks directly overlying the uppermost Permian coal seam. The sudden absence of peat-forming glossopterids was reminiscent of Sydney Basin's Frazer Beach Member (McLoughlin et al., 2021) and its stratigraphic equivalents across eastern Australia (e.g., the 'Marker Mudstone'; Michaelsen et al., 2000; Wheeler et al., 2020). This distinctive stratum has been linked to a biostratigraphic 'dead zone' (Vajda et al., 2020) and hosts a palaeontological signature typical of the end-Permian event. The 'dead zone' includes microfossil proxies for increased wildfires (Mays & McLoughlin, 2022), algal blooms (Vajda et al., 2020; Mays et al., 2021b) and extremely low primary productivity (Mays et al., in press). We expected to see a similar story, but finding Tasmania's 'dead zone' has not been trivial.

Magmatic minefield

Without exception, the outcrop samples were functionally barren of spore, pollen or alga fossils. Shreds of these were visible, but these appeared to have been thoroughly 'cooked': thermally matured beyond recognition. In parallel with our outcrop targets, we also collected and prepared a series of reconnaissance samples from bore cores around the basin (Fig. 3). At first, these yielded similar dismal results. The Tasmania Basin was marked by intense Early Jurassic magmatism as part of the Karoo-Ferrar Large Igneous Province (Ivanov et al., 2017; Fig. 1A). Consequently, many Upper Parmeener Supergroup sections have been intersected by intrusive dolerites and subjected to complex thermal maturation histories, contributing to poor recovery of organic microfossils in many parts of the basin (Banks & Naqvi, 1967; Forsyth, 1989).

If ever there was a place on Earth which illustrated the long-lasting impact of mass extinctions, Tasmania would be it. The end-Permian event has been linked to prodigious magmatism in Siberia (e.g., Reichow et al., 2009): the timing (~252 Ma), and magma-triggered climatic changes have been clearly linked to this extinction interval. Similarly, the Karoo-Ferrar Large Igneous Province has also been consistently linked to a mass extinction, albeit a second-order mass extinction, called the Toarcian Oceanic Anoxic Event (Burgess et al., 2015). However, this latter event was far later (~182 Ma, Toarcian Age, Early Jurassic). The signature of the worst mass extinction is written in the rocks, even if this signature has been partly smudged by the thumbprint of a later mass extinction. The scale of Karoo-

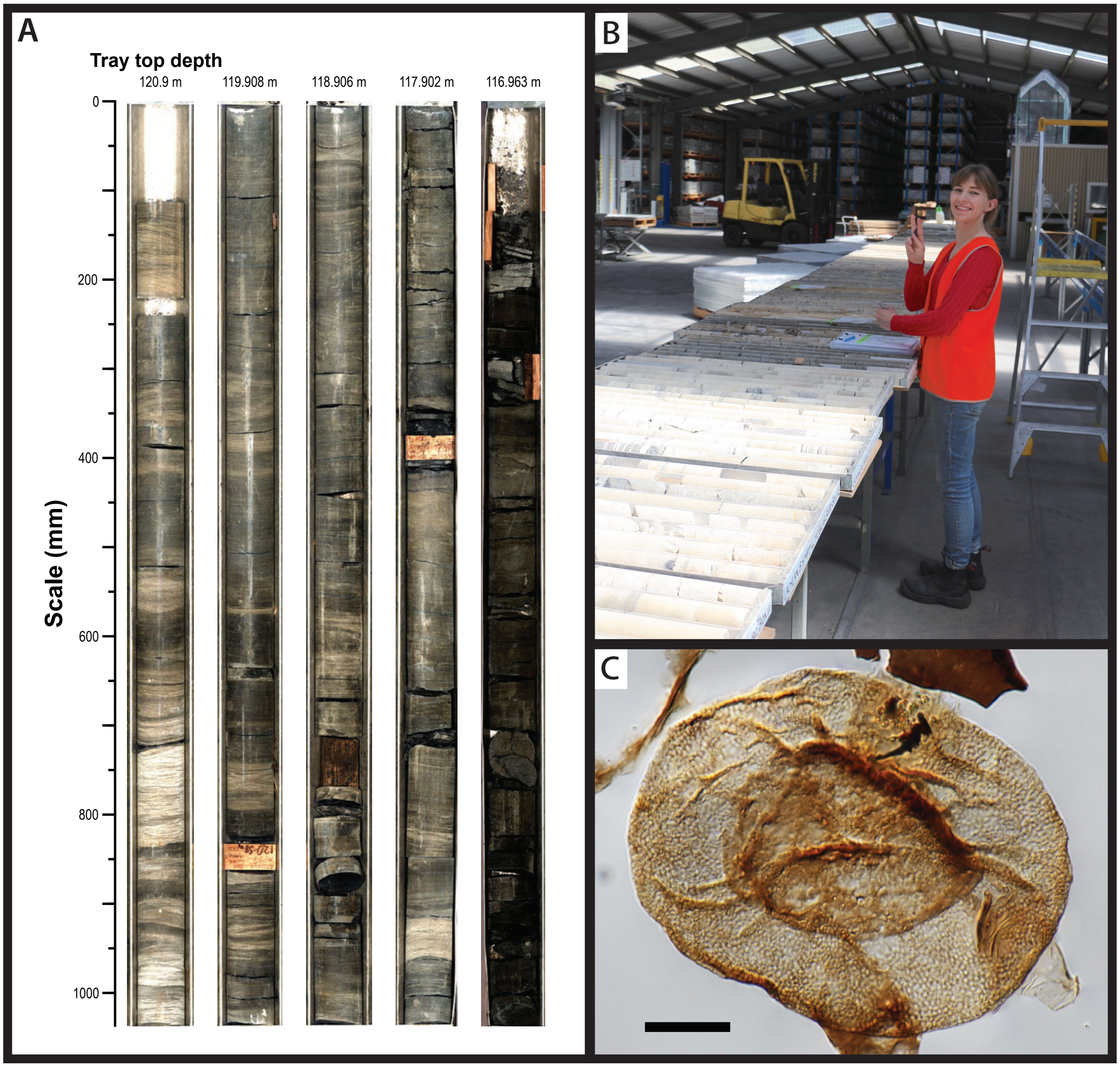

Fig. 3. Uppermost Permian cores and microfossils of the Tasmania Basin. A. A core section of the upper Cygnet Coal Measures from southern Tasmania Basin that preserves fossil and geochemical evidence of the end-Permian event. B. Core sampling at the Mornington Core Library, Mineral Resources Tasmania. C. A key index taxon for the uppermost Permian biozones of eastern Australia, Playfordiaspora crenulata, scale = 20 μm.

Ferrar magmatism is staggering: it stretches from southern Africa to Tasmania, which would have been >5000 km at the time. The volume of the sills alone is over half a million cubic kilometres (Svensen et al., 2018). After several dead ends, we identified two cores that appeared to have avoided heavy alteration from this swarm of Jurassic intrusions, while ticking both of our key criteria: 1, record the EPE; and 2, yield identifiable palynological assemblages (Fig. 3). The key results are presently being written up for publication.

Conclusions

Tasmania boasts some spectacular Upper Permian to Lower Triassic outcrops, complemented by a number of cored successions across the basin. The sediments and geochemical signals have given us a wealth of information on correlating these strata regionally and globally. To our great relief, the palynology too can be a fruitful avenue, with enough patience. While the key findings are still on their way, we can confirm that this area provides a fantastic snapshot of polar life during the EPE, and a correlation pathway to Antarctica.

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Report of field work in the Permian of Oman

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At the beginning of February 2023, three Italian researchers from the University of Milan, Lucia Angiolini, Marco Viaretti and Alessandro Paolo Carniti, guided by Alan Heward, a retired petroleum geologist from the UK, visited the Ash-Sharqiyah South Governorate, Sultanate of Oman to sample fossiliferous beds of the Permian Qarari Unit. An Omani geologist, Mohammed Al Kindi, joined us for the first two days.

The goals of this fieldwork were:

1) To sample the brachiopod fauna, with the minimum sample size approach, avoiding the bias towards well-preserved specimens which may be present in previous collections (Viaretti et al., 2022).

2) Identify and discriminate the localities, particularly those at Wadi Khawr al Jaramah, previously grouped into a single location;

3) Collect samples for conodonts to refine the age-range of these outcrops;

4) Have a general understanding of the geology of the area, which is understudied due to the nature of the terrain and the outcrops.

We spent the first three days in the area of Wadi Khawr al Jaramah (WKJ), near the town of Al-Hadd (Fig. 1, 2). The geology of the area is complex. The Qarari Limestone crops out in five locations, mainly as hills or small outcrops with beds extremely rich in fossils which have been previously assigned an age straddling the Kungurian-Roadian boundary (Viaretti et al. 2022). Here, not only brachiopods are extremely abundant and easy to collect, but well-preserved trilobites (Fortey and

Fig. 1. The outcrop of WKJ 1 on the right of our car.

Fig. 2. Group photo on the outcrop of WKJ 5. From left to right: Marco Viaretti, Alessandro Paolo Carniti, Alan Heward, Lucia Angiolini.

Heward, 2015) are part of the fauna (Fig. 3), along with corals, ammonoids, crinoids, blastoids, fusulinids, bryozoans and gastropods. Only two of the WKJ outcrops contain fossils in the rock matrix, allowing a detailed in situ palaeoecological analysis.

The outcrops are part of what was called the "Batain Mèlange" of Shackleton et al. (1990) or the Batain Nappes of Peters et al. (2001) and comprise rock units ranging from the Permian to the Late Cretaceous, of very different lithologies, from limestones and marlstones to radiolarites and red shales and basalts (Fig. 4). The outcrops were originally considered a part of the Hawasina Complex thrust over the NE margin of the Arabian Plate from Neo-Tethys. They are now interpreted as having been thrust from the SE out of the proto Indian Ocean. The excellent preservation of fauna in the Qarari Unit is a consequence of rapid burial during storm events, the marly character of the sediments at some localities and the overall shallow burial (CAI = 1).

In the afternoon of the third day we visited an outcrop at the side of a graded road to Shiya (SH), west of the WKJ outcrops. The locality is again represented by a small hill in the desert landscape. The preservation of fossils is different from the WKJ

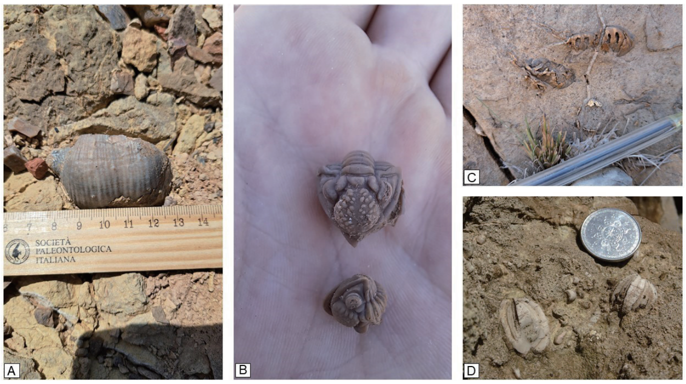

Fig. 3. A. *Callytharrella websteri* Viaretti et al., 2022; B. *Hentigia ornata* Fortey and Heward, 2015; C. Lyttoniid brachiopods on Jebel Qarari crest; D. Blastoids at Jebel Qarari.

Fig. 4. Radiolarites in the Wadi Khawr al Jaramah area. A.P. Carniti for scale.

localities: here the brachiopods are strongly silicified. This outcrop is also characterized by the presence of many lyttoniid shells, previously recorded by just two encrusting specimens of *Eolyttonia* (Viaretti et al., 2022).

The fourth day we headed south toward the Jebel Qarari and Jebel X outcrops. Along the road, we stopped at an outstanding arch of Permian rocks, from which the breathtaking view on the mountains behind made for a perfect place to take a group photo (Fig. 5). The Permian rocks contains fusulinids, and have been previously referred to as Lopingian (Baud and Bucher, 2022). Collecting samples from the arch is not possible since it is a Oman geoheritage site.

On our way south to Al-Ashkhara we also stopped at a section near Bu Fashiqah published by Hausher et al. (2000) and Peters et al. (2001). The outcrop does not contain shallow-water fossils except in a rudstone bed with trilobite sclerites. The Qarari Unit is here capped by the mega-breccias of the Aseelah Unit, but the lithological boundaries are not easy to trace, and we spent some time trying to follow the log of the section. In the afternoon we visited the Jebel X localities near Jebel Qarari, climbing a steep path to reach the outcrops. The reward was the possibility to collect many brachiopods from three different lithologies: the "green grits" (Shackleton et al., 1990), a pink crinoidal

Fig. 5. Group picture at "The Arch". From left to right: Alan Heward, Lucia Angiolini, Alessandro P. Carniti, Marco Viaretti.

Fig. 6. Fieldwork in the wadi section at Jebel Qarari. From left to right: Lucia Angiolini, Alan Heward and Marco Viaretti.

calcarenite/calcirudite and a conglomerate.

The last day of fieldwork we climbed Jebel Qarari and collected samples both from the crest and wadi at the base of the mountain. Along the crest the preservation of the brachiopods is similar to that at SH: highly silicified material preserved in hard limestones, making it difficult to collect specimens. As at Shiya roadside, we found several lyttoniids (Fig. 3). In the wadi we identified nine overturned beds, and collected as many brachiopods as possible (Fig. 6). At the end of the fieldwork we had collected around 35 kg of fossil samples and four blocks for the study of conodonts, which we sent to Charles Henderson in Calgary, Alberta, Canada.

Before leaving Oman, we visited the Natural History Museum in Muscat, to present them with specimens of new species described from these localities (Viaretti et al., 2022). We also spent time with the Research and Geological Survey Directorate of the Ministry of Energy and Minerals obtaining permits for the export of samples.

The faunas of these outcrops differ from those of the Wordian

Khuff Formation (representative of the Arabian Plate) and those from the Oman Exotics (representative of Neo-Tethys).

Even if not easy to reach and find, these fossiliferous beds of the Qarari Unit are crucial to understanding the Cisuralian-Guadalupian transition and biotic change, and may be a focus of a future field trip for interested Permian workers.

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A report of the Sino-German Cooperative Group in Late Paleozoic Paleobiology, Stratigraphy and Geochemistry

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During 2010-2014, an international cooperative project jointly led by Xiang-dong Wang and Hans Kerp and funded by both National Science Foundation of China (NSFC) and Deutsche Forschungsgemeinschaft (DFG) was carried out by both Chinese and German paleontologists and stratigraphers. Quite a few joint workshops and field excursions were organized in China and Europe, which produced many high-impact publications (e.g., Scholze et al., 2016, 2020; Schneider et al., 2020). The general objective of the Sino-German Cooperation Group is to offer an open platform for international cooperation on the palaeobiology, stratigraphy and geochemistry of China and Europe. The scientific cooperation will focus on stratigraphic correlation of the terrestrial and marine deposits of the Carboniferous and Permian systems between the western and eastern Palaeo-Tethys and adjacent land masses. Although the bilaterally-supported project was finished a few years ago, the cooperative joint research has never ended. In July, 2023, another joint field excursion was organized by German and Chinese geologists (Fig. 1). The main purpose was to investigate the Permian-Triassic interval at Caaschwitz Quarry, a transitional section from the marine Zechstein (Lopingian) to the terrestrial Lower Buntsandstein (Early Triassic) (Scholze et al., 2017).

The large outcrop of the former surface mining of Zechstein Cycle 3 dolomite (Leine Fm.) is situated north of the town Gera in Thuringia (central Germany). The uppermost Zechstein Cycle 7 (Fulda Fm.) is composed in the lower part of sandy siltstones of sabkha facies, and in the upper part of red, fine to coarse grained sandstones and red-brown siltstones of fluvially-influenced playa-lake facies (dark red-brown level in Fig. 1). Above are the fluvio-lacustrine sandstones with flaser/lenticular bedding, ripple marks and desiccation cracks of the lower Calvörde Formation (basal Lower Buntsandstein). The Permian-Triassic boundary is likely to be situated in the upper Fulda-Formation based on multistratigraphic investigations (Scholze et al., 2016, 2017) (Fig. 2).

Fig. 1. The joint Sino-German research team at Caaschwitz Quarry in July, 2023. From left: Guanyi Wei, Feifei Zhang, Yukun Shi, Shuzhong Shen, Joerg W. Schneider, Frank Schozle, Xiangdong Wang, Hua Zhang

During the field investigation, detailed samples across the Permian-Triassic transition were collected. In addition, core samples from the same interval were collected as well. The joint research team will concentrate on biotic changes and events in the terrestrial environments, particularly in response to environmental and climatic changes. A series of geochemical proxies will be tested to understand the causes and effects of geochemical changes in natural environments during the Permian and the Triassic. The results from Europe will be compared with the counterpart results from North China and Northwest China.

It is envisaged that a formal Sino-German Cooperation Group will promote further collaboration, but not just for the duration of the project. Our ultimate goal is a close and strong long-term collaboration. The central theme, the paleobiological and paleoclimatic evolution of the late Paleozoic, offers many avenues for collaboration and exchange.

Fig. 2. The Permian-Triassic sequence at Caaschwitz Quarry. Left side, lower part of the photograph: red, fine-grained siliciclastics of the Upper Fulda Formation (upper Z7 Cycle, uppermost part of the Zechstein Group). Upper part of the photograph: grey-yellowish and red, course- and fine-grained deposits of the Calvörde Formation (Lower Buntsandstein Subgroup, Buntsandstein Group).

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ANNOUNCEMENTS

On July 20, 2023, Markus Aretz has informed us that the next ICCP will expanded to include also the Subcommission on Devonian Stratigraphy. The "GeoTolosa 2025 - News from the Palaeozic worlds" will thus be held in Toulouse, France in late June 2025. The first circular will be available in early June 2024.

SUBMISSION GUIDELINES FOR ISSUE 76

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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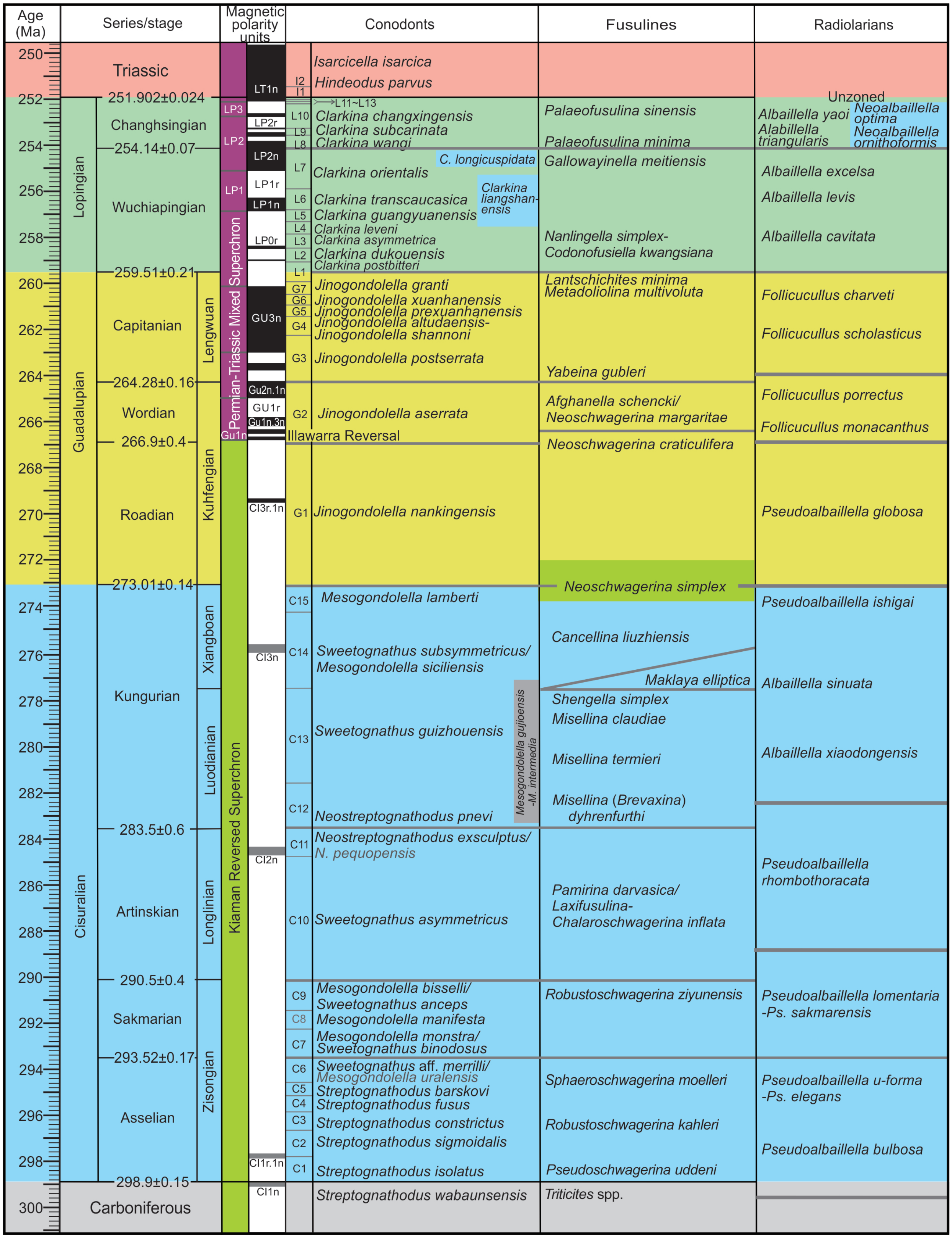
The deadline for submission to Issue 76 is December, 31, 2023



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