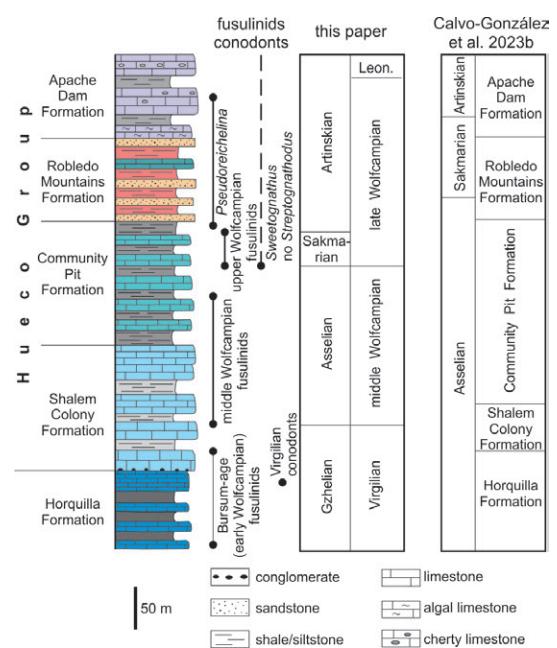
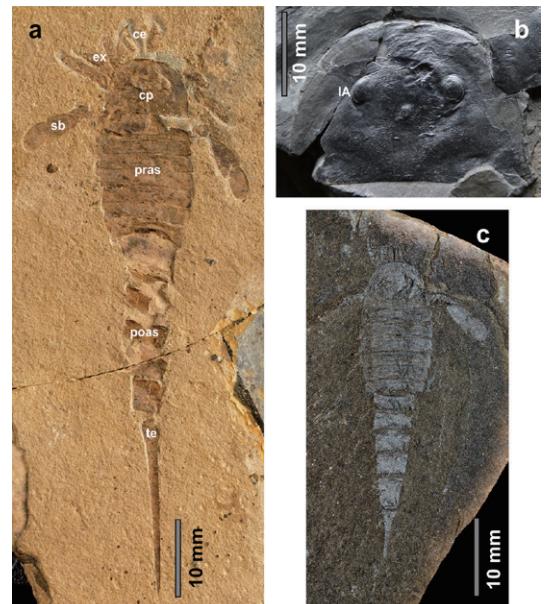




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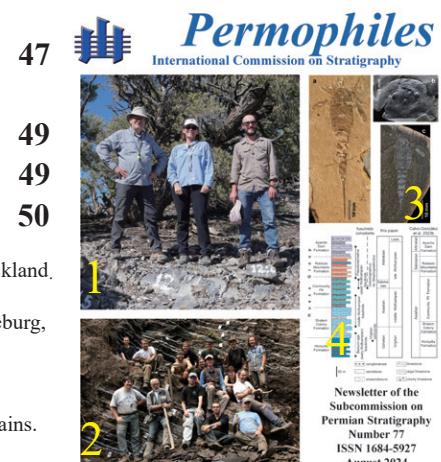
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Fig. 1. Charles Henderson, Lucia Angiolini and Mike Read standing above base-Kungurian GSSP candidate of Rockland. Angiolini et al., this issue.

Fig. 2. Excavation team of 2012 to study and restore the Geotope Lochbrunnen near Oberhof. Schneider and Werneburg, this issue.

Fig. 3. *Adelophthalmus* sp. from the Asselian Lower Goldlauter Formation, Thuringian Forest. Schneider and Werneburg, this issue.

Fig. 4. Summary of Hueco Group lithostratigraphy and some important biostratigraphic data in the Robledo Mountains. Lucas et al., this issue.



Notes from the SPS secretary Yichun Zhang

Introductions and thanks

At the end of July and early August, 2024, I received many submissions to this issue of *Permophiles*, during my fieldwork in Tibet and also after I have returned to Nanjing. Now, I am editing this issue in the hot summer (about 40 °C) of Nanjing. This high temperature mirrors the enthusiasm of our Permian colleagues. As you can see in this issue, many debates arose with respect to several Permian topics, including Permian chronostratigraphy and their correlations. This is always the characteristic of our Permian community.

As demanded by IUGS EC, all subcommissions of ICS have to adhere to the Statutes. So, at the IGC in Busan in this month, the SPS executive will be slightly renewed. Dr. Liz Weldon has been elected as the new SPS Chair for the next term (2024-2028). Here, I would like to thank SPS Chair Prof. Lucia Angiolini for her great contribution to the Permian subcommission. During the past four years, under the leadership of Lucia Angiolini, the base-Artinskian GSSP was ratified by ICS and IUGS. Also, the base-Wuchiapingian GSSP was redefined and a new SABS of this base was established. In addition, several webinars covering many Permian subjects were organized by SPS, and the videos can be accessed in SPS website. Also, selected papers published on Permian topics were compiled by Lucia Angiolini for every year since 2020. This is very convenient for Permian scholars. Thanks to Lucia for her productive work. I trust our new SPS executive will continue to work hard for our Permian community led by the new Chair Liz Weldon.

This issue of *Permophiles* contains diverse articles, including comments and replies about Permian GSSPs and correlations, paleoclimate studies using fossils, big data applications in taxonomy. *Permophiles* always acts as a good platform for scientific papers, comments and replies and any other articles related to Permian studies. Thanks to all contributors of this issue: Charles M. Henderson, Benoit Beauchamp, Lance L. Lambert, Lucia Angiolini and co-authors, Spencer Lucas and co-authors, Michael H. Stephenson and co-authors, Joerg W. Schneider and Ralf Werneburg, Marco Viaretti, Yan Chen and co-authors, Cesare Perotti and Ausonio Ronchi, and Karl Krainer.

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As usual, this issue starts with the Henderson's Harangue #13. He continues to highlight the significance of the Geological Time Scale. Also, in the following contribution, Charles M. Henderson and Benoit Beauchamp reply to the comments by Vladimir I. Davydov in *Permophiles* 76. They reviewed the process of the establishment of the base-Sakmarian stage and acknowledged that the choice of FAD of conodont *Mesogondolella monstra* is the best choice for marking the boundary. They also discussed the discrepancy between the fusulinids and conodonts biochronology.

Lance L. Lambert responds to the contributions by Spencer G. Lucas and Charles M. Henderson in *Permophiles* 76. He suggests that the base of Roadian/Guadalupian GSSP in Road Canyon is workable in terms of the conodont lineage *Mesogondolella* to *Jinogondolella* as well as the distinct eustatic signal that will help facilitate worldwide correlation.

Lucia Angiolini and co-authors report their recent fieldwork in the Rockland Section (Kungurian GSSP candidate section) at Rockland of Nevada, USA. The detailed fusulinids sampling in this section will aid in the establishment of base-Kungurian GSSP. They also studied the upper Asselian to upper Artinskian succession at the Carlin Canyon aiming for base-Sakmarian and base-Artinskian SABS.

Spencer G. Lucas and co-authors comment on a study by Calvo González et al. on the ages of the Hueco Group. The revised ages based on fusulinids and conodonts on the Horquilla, Shalem Colony, Community Pit, Robledo Mountains and Apache Dam formations are different from the age assignment of these formations by Calvo González et al. Consequently, the explanation of the Late Paleozoic Ice Age in both studies are different.

Michael Stephenson and co-authors introduce the application of artificial intelligence in palynological taxonomy. The Large Language Model (LLM) Taxonomic keys and values based on text has potential for a correct taxonomy identification, which has great application in science and a commercial environment.

Joerg W. Schneider and Ralf Werneburg introduce the new book "Die Rotliegend-Fauna des Thüringer Waldes" and summarize the contents of 19 chapters.

Marco Viaretti and Lucia Angiolini report their recent work on the oxygen isotope on the Wuchiapingian brachiopod shells from the Julfa and Abadeh sections in Iran. The result shows a cooling interval of about two million of years, which is in agreement with other studies. This study is significant in revealing the high-resolution climatic change during the early Lopingian.

Yan Chen and co-authors summarize their recent publication in the journal *Global and Planetary Change*. They suggest that normal-polarity chron LT1n began after the onset of the LPME and prior to the PTB, which serves as an important marker for high-precision correlations of LPME and PTB.

Joerg W. Schneider provides a short abstract of a recent paper by Belahmira et al., published in the journal *Newsletters on Stratigraphy*.

Lucia Angiolini and Uwe Brand report about the 9th International Brachiopod Congress held in June in Ontario, Canada.

Sadly, two obituaries are released. We acknowledge Prof. Giuseppe Cassinis and Prof. Danial Vachard for their great contribution to Permian studies.

Finally, the 6th International Conodont Symposium and GeoTolosa ICCP meeting are announced, which will be held respectively in Brazil in December, 2025 and in France in June, 2025.

Future issues of *Permophiles*

The next issue of *Permophiles* will be the 78th 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 78 is 31 December 2024. Manuscripts and figures can be submitted via email (yczhang@nigpas.ac.cn) as an attachment.

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

Notes from the SPS Chair

Lucia Angolini

This is my last “Notes from the SPS Chair”, and I am proud that it introduces an issue which is rich in replies and critiques, showing that *Permophiles* has become a forum for discussion and that it functions in its role in building the Permian community and conveying Permian research.

In the last few months there was some debate concerning procedures inside SQS and the voting on the Anthropocene proposal. One fallout from the events was a demand by the IUGS EC that all the subcommissions of ICS adhere to the Statutes. (<https://stratigraphy.org/statutes>). The flexibility to allow subcommission voting members and executive as well as task/working groups to complete assignments is over.

To adhere to the rules for the term 2024-28, the composition of SPS voting members was slightly revised (and you will see the new composition in the website in September 2024), and a new SPS Chair candidate was selected respecting gender equality and geographic distribution: Liz Weldon from Deakin University, Australia, who is well known in the Permian Community for her interest and dedication to Permian studies and for her managerial skills. A call to vote on the new SPS Chair candidate Liz Weldon was sent to the SPS Voting Members on 24th March 2024, with the request of returning the vote by the 24th April 2024. The result was a 13-3 vote in favour (81.25%).

On July 2024, the IUGS Executive Committee reviewed the list of persons put forward as officers and voting members for SPS for the term 2024-2028 and approved them.

It is thus my pleasure to announce the new SPS Executive, who will start the term in September, 2024:

SPS Chair Dr. Liz Weldon

SPS Vice-Chair Prof. Mike Stephenson

SPS Secretary Prof. Yichun Zhang

The SPS Executive for the term 2024-2028 comprises very active and experienced people from three continents, and with different expertise: they all have my respect and my full trust for successful management of SPS in the future.

As I wrote in *Permophiles* 76: “there is a lot to do for the Permian, a huge amount of work that can be summarized in three words: complete, redefine, correlate”.

SPS will have to complete the Permian Time Scale: only one Permian GSSP remains to be defined, the base of the Kungurian, but a lot of progress has been made in this direction. A field-trip to the Rockland section (Nevada), base-Kungurian GSSP candidate, was held in May 2024. Preliminary results to collect fusulinids and also brachiopods for additional Sr analyses are reported in this issue of *Permophiles*. We plan to have the proposal of the base-Kungurian GSSP published in the next issue of *Permophiles* and then voted on by SPS voting members.

The Guadalupian GSSPs reveal some problems. As discussed in *Permophiles* 76, voting members unanimously reached the conclusion that the base-Wordian should be redefined. The opinions about the base-Roadian GSSP are different, and this GSSP may need a more detailed description, but the contribution of Lance Lambert in the present *Permophiles* issue is enlightening.

Two Working Groups were erected in 2024 to solve the problems of the Guadalupian GSSPs.

A never-ending goal that SPS should continue to aim toward is to correlate. There is need to intercalibrate non-marine with marine records and solve the problems of correlating terrestrial Permian deposits with marine successions on which the Standard Global Chronostratigraphic Scale is based: A Working Group lead by Joerg Schneider has been very active on this. There is also a need to develop correlations between Permian Tethys successions and elsewhere. Gondwana to Euramerica correlations must be improved. SPS also needs to discuss the revision of past correlations, as shown by the critiques and replies published in the previous and current issues of *Permophiles* (Carnic Alps, Canadian Arctic-Urals, Robledo Mountains cases).

A topic that has been recently debated in the Permian Community as well as the wider stratigraphic community is the challenge of the concept of the GSSP. We need to develop international standards to reconstruct a global chronostratigraphic framework and communicate unambiguously about geological time. This can be achieved by defining Global boundary Stratotype Sections and Points (GSSPs), which are reference points within actual stratigraphic sections of rock that define the lower boundaries of stages on the International Chronostratigraphic Chart.

What is sometimes forgotten or misrepresented is that a GSSP is a point in a rock succession. The primary marker is often a biological event, but it doesn't have to be. There is an historical tradition to use a biological event because they are easily identifiable and readily correlated. The primary marker for Permian GSSPs has become the FAD of a conodont species. This has led many to challenge the GSSP concept. However, the primary marker and other markers at or near the point, including other fossils, geochemistry, magnetostratigraphy, interpolated radiometric ages, etc. are required to be used to correlate the boundary stratotype - not to define it. We therefore need the entire community of researchers to cooperate, communicate and collaborate if we want to successfully correlate our stage boundaries!

An example? The base Sakmarian GSSP is defined at a point in bed 26/3 of the Usolka section. The boundary is correlated by the FAD of *Mesogondolella monstra*, and an additional conodont bioevent (FAD of *Sweetognathus binodosus*), an extrapolated age based on two ash beds, a ⁸⁷Sr/⁸⁶Sr isotopic value, two negative $\delta^{13}\text{C}_{\text{carb}}$ excursions, and fusulinids, ammonoids, brachiopods and palynology; all are essential to aid correlation (Chernykh et al. 2020, *Episodes* 43/4).

The first Permian GSSP (the base Asselian GSSP at the base of the Permian) was ratified in 1996. The process is long and needs extensive and multidisciplinary studies and global consensus; the last Permian GSSP will be hopefully ratified next year. This means that SPS has been active, but also accurate and conscientious in establishing the standards for the Permian Time Scale. I am sure the new officers and voting members will continue on this path.

To conclude my notes, I would like to express my warmest gratitude to Mike Stephenson and Yichun Zhang who have

worked with me constantly and efficiently in these four years of leadership in SPS: thank you for your very good ideas and time spent in constructive and brilliant discussions, and for having shared with me the success of our SPS webinars and *Permophiles* issues.

I would like to thank Charles Henderson for his friendship, for having always been present for discussion and strong support, and for his invaluable contributions to *Permophiles*. Congratulations Charles on your new appointment as ICS Secretary-General!

I have sincerely appreciated the interesting, motivated and always thoughtful *Permophiles* contributions of Spencer Lucas and Joerg Schneider, and the activity of Shuzhong Shen, who is constantly performing high-level Permian research.

I would like to express my gratitude also to Liz Weldon, for having accepted the honour and burden of being the next SPS Chair. With Mike and Yichun you will make a very good Executive!

Last but not least, my deepest thanks to the voting members for the term 2020-2024 and to all that have contributed with their studies, communications, ideas, and suggestions to Permian research and SPS.

It has been an honour to serve SPS and I will continue to contribute to Permian research and the community.

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- 1) Kungurian-base GSSP Working Group; Chair: Charles Henderson.
- 2) Correlation between marine and continental Carboniferous-Permian Transition Working Group; Chair: Joerg Schneider.
- 3) Gondwana to Euramerica correlations Working Group;
Chair: Mike Stephenson.

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Henderson's Harangue #13

Charles M. Henderson

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Resistance to Change

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

In this issue of *Permophiles* there is a well written critique of some recent correlations based largely on conodonts in the Hueco Group of the SW USA. Previous correlations of these units were based on fusulinids correlated with the American stages Wolfcampian and Leonardian before the production of the Lower Permian GSSPs. In the last issue (*Permophiles* 76) there was a critique related to recent correlations based largely on conodonts in the Permian units of Austria. Previous correlations of these units used fusulinids correlated with international stages (Asselian, Sakmarian and Artinskian) and regional substages before the production of the Lower Permian GSSPs. There was also a critique of major correlations using small foraminifers, fusulinids, and conodonts within the Permian units of the Sverdrup Basin in the Canadian Arctic. Benoit Beauchamp and I have written a reply to this critique that appears separately in this issue of *Permophiles*. All of these critiques are useful for discussion and will improve our time scale correlations, but the changes do not seem as great as suggested. In my view, they mostly demonstrate a resistance to change – a resistance to use our ratified Lower Permian GSSPs or perhaps a desire to cling to the past and return to the good old days when our stage boundaries were moving targets.

Let me outline a potentially futile task. Start with a fusulinid succession in Russia based on numerous taxa and compare this to a fusulinid succession in SW USA many of which have different names and then compare this to a fusulinid succession in South China with even more different taxonomic names. Now develop a single zonation with consistent correlations among all regions to which everyone agrees. Conodont workers then develop a zonation and correlations that somehow seems different, not to mention that many conodont workers may disagree on taxon names. All this occurring during a time when there was no single standard definition for each of the Lower Permian stages and everyone was free to pick their favourite floating target that might work well in one region or one part of a basin, but not so much in another. What do you do? Throw your hands up saying "this is futile". Alternatively, we could develop working groups that include workers of many fossil clades (especially fusulinids, conodonts, ammonoids, and brachiopods) as well as geochemists, sequence stratigraphers, and geochronologists. Their task is to develop a chronostratigraphic framework that will ultimately yield Global Stratotype Sections and Points (GSSPs) for the Lower Permian stages. Well we did this! Mission accomplished for the Asselian, Sakmarian, and Artinskian and nearly done for the Kungurian. The points were located by conodont species appearances, but the definitions are actually - the point. Moving

laterally from the points we correlate the boundaries using many stratigraphic tools, including fusulinids. However, the ultimate futile task seems to be asking everyone to adhere to these definitions and adjust their local zonal correlations accordingly. No need to change the zones, just the correlation and age assignment, but the resistance to change seems great.

We live in interesting times – which is a nice way to speak of the present. The political left and the right love very much to talk or protest, but they do not wish to listen to each other. Climate change is changing the world in which we live, but we cannot seem to agree what to do about it. Some say it is not really a big deal, others say it is a potential disaster that requires us to change the way we live completely, and others say we could adapt. Finding a feasible and realistic resolution will require these different groups to do something novel – they will need to listen to each other. Geologists know that change is inevitable and through their research have shown how much and how often our planet has changed through the ages. Whether we study the Proterozoic, or Permian, or present day there is so much to learn about planet Earth. Stop for a moment and marvel at that last sentence! No, not for my prose, but rather the opportunity to travel back where the past can again reenter. The ability to speak of those past times is perhaps our greatest invention. It is inspiring to be able to describe the first complex multicellular life of the Ediacaran biota, to tell how sail-back reptiles roamed the land next to seas swarming with small eel-like organisms with microscopic teeth, and finally to learn how fragile our planet really is. We can do this because of the Geologic Time Scale. Given the intrinsic value of the GTS we really should aim for the most practical, stable and precise time scale – this is the primary goal of the GSSP concept.

The GSSP process, like democracy, is not perfect, but it does provide definitions and removes the moving targets of the past. The Sakmarian and Artinskian stages were ratified in 2020 and 2023; the authors of the *Episodes* articles included (in alphabetical order): M.S. Afanasieva, Lucia Angiolini, Valery Chernykh, Boris Chuvashov, T.V. Filimonova, Charles Henderson, T.N. Isakova, Ruslan Kutygin, Shuzhong Shen, Michael Stephenson, G.M. Sungatullina, R.Kh. Sungatullina, and Dongxun Yuan. That is quite an international group with Canada, China, Italy, Russia, and the UK represented. The *Episodes* articles were peer reviewed by experts. Furthermore, the proposals were developed and evaluated by a working group and voting members of the Subcommission on Permian Stratigraphy. Their research cited the work of many other international workers that study all of the different ways we learn about stratigraphy. Later all of the subcommission chairs of the International Commission on Stratigraphy vetted and voted on the document and finally the executive of the International Union of Geological Sciences checked it one more time and ratified it. Wow! Such an extraordinary research effort deserves a celebration!

So what is wrong with the process that many call for its downfall? Perhaps the most prolific critic is Spencer Lucas (see this issue and several others of *Permophiles*). I should be offended since I am a defender of the GSSP concept, but Spencer and I have an interesting relationship. In addition to the critiques and replies, we have produced recently some good

papers together and have a couple more in production. I enjoy talking to Spencer and listening to him. He indicates that using conodont speciation events and their inherent diachroneity as the primary signal lends instability and imprecision to the time scale. He indicates that natural events would be better suited as practical signals. For example, why not use the end-Permian mass extinction (EPME) rather than the evolution of *Hindeodus parvus* as a primary signal to correlate the Permian-Triassic boundary. The FAD of *Hindeodus parvus* at Meishan Section D is used to choose the point defining the PTB and at this location, it is immediately above the sudden EPME. However, to correlate the PTB many tools are used including magnetostratigraphy, isotope stratigraphy, geochronology, and speciation events including, but not limited to, *Hindeodus parvus*. Interestingly and rarely appreciated, is the fact that the extinction in NW Pangea occurred much earlier and over a protracted interval, largely related to the geographic variability of effects associated with this greenhouse climate change event. The appearance of any species is often diachronous and affected by facies and sampling strategy, but in this case the extinction is likely much more diachronous. One other signal, particularly useful for correlation, is the transgression that began in the Late Permian 252 Myrs ago and continued into the Triassic. This leaves a distinct eustatic signal that can be correlated worldwide.

Transgressions are the revolutions of stratigraphy, which challenge a natural order and change becomes necessary. They represent natural events and leave their physical mark on the landscape and within rock successions that is unaffected by time. This places natural selection pressure on many organisms in the oceans and on the land. Terrestrial regions are reduced in area, affecting the survival of land-based animals – some undergo adaptive evolution. Transgressions also provide the accommodation for terrestrial deposition and preservation, which is not the case during sea-level fall. In the marine realm, many species evolve during the initial transgression and, if successful, become fully established and distributed globally by the maximum flooding surface. Conodont zones are often concentrated within transgressive successions and the base-Sakmarian and base-Artinskian are perfect examples (see the Henderson and Beauchamp reply elsewhere in this issue). The remainder of a depositional sequence is when everything is finally sorted out. Benthic organisms like fusulinids and brachiopods evolve to a different beat, which provides the opportunity for even more zones within a depositional sequence.

The use of non-biotic, quantitatively established numerical ages to define GSSPs has been suggested. I am not sure what criteria you would use to choose a particular ash bed over another. They seemingly appear randomly and are not necessarily associated with a recognizable stratigraphic event although there is likely a measurable tectonic pulse. I would suggest these numerical ages should take an even more important role – as the arbiter or judge. There is no question that the precision of geochronology today provides many ways to test current correlations, or to decide among opposing schemes, and to determine evolutionary rates. To me, research on those topics, would be much more interesting than endless critiques and replies.

We are fighting the forces of nature when we focus our attention on resistance to change. Using the geological time scale will allow us to better correlate natural events like the waning of the late Paleozoic ice ages, which for a time had many high frequency transgressive-regressive sequences (cycloths of the Gzhelian and Asselian). The amplitude of these sea-level fluctuations reduced in the latest Asselian, probably in association with diminished ice-volume. The Sakmarian and Artinskian are marked by major flooding events, but there may be evidence of high-frequency cycles in north-central Texas well into the Artinskian. We should focus on more precisely resolving the timing of these events.

These times are going by very quickly and seem to have an urgency now, so I make one last plea to use our Geological Time Scale – we now have definitions rather than moving targets to constrain our interpretations. You can find the latest version at stratigraphy.org.

Reply to “The crisis in the global Permian correlation – Canadian Arctic-Urals case” by Vladimir I. Davydov (2024) in *Permophiles* 76

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Preamble

Every crisis is both potentially a catastrophe and an opportunity. We see this one, if it is a crisis, as an opportunity. One of the consequences of defining Global Stratotype Sections and Points (GSSPs) is that it leaves a single unequivocal point for correlation. This seems like a desirable goal, but not everyone likes the concept. Spencer Lucas has led this charge and his critiques (see his articles in *Permophiles* 68, 76, and references therein) provide the opportunity to communicate, improve the GSSP process, and refine our correlations. It is argued that reliance on a single biotic event (especially the First Appearance Datum of a conodont species) for boundary definition is impractical and leads to imprecise and unstable boundaries. However, it is important to remember that the boundary is not **defined** by any FAD, but rather a **FAD marks** or provides a rationale for choosing a point in a section to serve as GSSP. All available methods are considered for correlation of that point including the ranges of other fossils, geochemistry, especially isotopic excursions, magnetostratigraphy, sequence stratigraphy, and radiometric age dating, if ash beds are available. Logistics and costs often determine how many of these tools are employed in each case, but every GSSP proposal provides multiple tools for correlation. In fact, it is a requirement for the proposal to be considered by the International Commission on Stratigraphy (see stratigraphy.org)! The situation before the GSSP concept was one of a moving target. In other words, boundaries could have different definitions.

When one of us (CMH) attended the Carboniferous-Permian congress in Beijing in 1987 as a graduate student there were at least two very different “definitions” for the Carboniferous-

Permian Boundary. Communications opened up during that meeting eventually led to a definition for a single level. We also have regional units like the Wolfcampian-Leonardian boundary (WLB) with at least three definitions. The WLB in Kansas at the contact between the Nolans cyclothem and Wellington Formation red beds is close to the base of Sakmarian (Henderson, 2018). Lucas et al. (2022) demonstrated that the upper Artinskian position best fits historical priority for the WLB by correlating the FAD of *Schwagerina crassitectoria*. It cannot be both levels, if it were it would be impractical, imprecise and unstable. In the past, with multiple regionally defined or even undefined definitions or poorly constrained correlations of a boundary, it was possible for everyone to be sort-of right. Now with a single defined boundary for each stage we have to decide the right correlation.

Reply

Vladimir Davydov (2024) has provided an alternate correlation model for the biostratigraphy and cycle stratigraphy reported for the Sverdrup Basin in the Canadian Arctic by Beauchamp et al. (2022a). We agree with Vladimir that the base-Tastubian should be redefined and that radioisotopic ages will always be very useful to constrain correlations. He makes a number of other interesting comments regarding the foundation for our biostratigraphic correlations. We will address these comments in the paragraphs below in roughly the order presented by Vladimir.

He accepts our correlations for the Gzhelian including 12 cycloths so the debate begins with the Permian. His revised correlations indicate a major unconformity with Sakmarian strata overlying Gzhelian. However, there is no evidence for such a profound unconformity in the region based upon the detailed sequence stratigraphic correlations presented in Beauchamp et al. (2022). These correlations were arrived at following at least 30 field seasons in the Arctic by us and our students. Vladimir indicates that our biostratigraphic correlations significantly deviate from previously established frameworks (for example, Boardman et al., 2009). This is true and many comments in *Permophiles* supporting these deviations have been documented (see Henderson, 2018). Vladimir also indicates that former correlations of the Lower Permian in the Canadian Arctic were generally in line with fusulinid biostratigraphy (for example, Harker and Thorsteinsson, 1960; Nassichuk and Wilde, 1977; Beauchamp and Henderson, 1994). The deviations are a result of two different actions. First, we have generated considerable new data over the years within projects designed to address specific correlation issues. Second, and most important, there are GSSPs now for the base-Asselian, base-Sakmarian, and base-Artinskian and this has necessitated revision of many previous published correlations. We have changed some of our original correlations to reflect our newly defined time scale. We have chosen to communicate these changes rather than defend the maintenance of an impractical moving target. It should not be expected that fusulinid biozonal and conodont biozonal boundaries will coincide. As sessile benthic organisms, fusulinid zones are often associated with shallowing (within the RST or HST of sequence stratigraphy). As nektic organisms, conodont zones are often associated with deepening (within TST or MFS). The GSSPs have been ratified, but correlations depend on both conodonts and

fusulinids and many other tools.

Davydov (2024) does not like the ‘redefinition’ of the Sakmarian. However, the GSSP (Chernykh et al., 2020) is the first truly international agreement on the correlation of the Sakmarian. The first two authors are renowned Russian paleontologists and geologists who agreed to the definition and correlation. Vladimir provides a history for how the position was determined, but one of us (CMH) will add a few details. There was a meeting in Boise with Valery Chernykh, Bruce Wardlaw and others including Vladimir (and there was vodka), where a position higher than the FAD of *Mesogondolella uralensis* was considered, because this species did not have a global distribution. It does not occur outside of the Uralian Basin, despite the unillustrated “identification by Wardlaw in eastern California”. It does not occur in Carlin Canyon (Beauchamp et al., 2022b) and it has not been recovered from the Garden Valley Formation in deposits very close to the Asselian-Sakmarian boundary (Wardlaw et al., 2015). A working group therefore considered a higher position associated with the FAD of *Sweetognathus binodosus* occurring above some transitional forms of *Sweetognathus* at the Usolka section. Valery Chernykh still preferred using the *Mesogondolella* lineage, and a few years later, when *Mesogondolella monstra* was found in many areas including Carlin Canyon, the Sverdrup Basin (Beauchamp et al., 2022a,b) and South China near the FO of *Sw. binodosus*, the working group decided to complete the GSSP proposal. This took a number of years and lots of research by an international group of experts to arrive at this decision. The base-Sakmarian stage was defined, but substages were not considered. Vladimir is right that this GSSP necessitates a redefinition of the Tastubian substage. However, ICS is currently focused on completing stage definitions and not substages.

Davydov (2024) attributes the timing of Henderson’s shift in correlations to the acquisition of unpublished radioisotopic dates

from the Apillapampa section in Bolivia. This has been discussed previously in *Permophiles* and in Henderson (2018), and it is true that those dates raised a number of concerns regarding some correlations. Eventually, this led Henderson (2018) to recognize two lineages of *Sweetognathus* and his MSc student Wyatt Petryshen (Petryshen et al., 2020) did an independent 3D morphometric study that pointed to the probability of parallel evolution. Vladimir suggests that questions still linger regarding how to effectively separate these two lineages and notes that the conodont assemblages in Bolivia and their age are not formally published. This is mostly true and work continues, but there has been progress. Henderson and Chernykh (2021) agreed that *Sweetognathus asymmetricus* marks the base-Artinskian and not *Sweetognathus whitei*. One of us (CMH) is working on a comprehensive paper on these lineages. One lineage originated during the Asselian in mid-west USA and/or Apillapampa and the second lineage originates in the mid-west USA, also during the Asselian (see Henderson, 2018; Petryshen et al., 2020). The second lineage was more successful in terms of temporal duration and geographic distribution and is being used for biostratigraphy. The Bolivia section includes fusulinids (studied, but not published by Davydov), conodonts (studied, but not published by Henderson), and ash beds (dated, but not published by Mark Schmitz except partly in abstract form and in emails and by di Pasqua et al., 2015, who did not request verification with the original authors). Mark has indicated that these dates can be restudied and that he could perform a Bayesian analysis using these dates and taxa assigned by Davydov and Henderson. If Mark agrees to be the arbiter, it should be possible for Davydov and Henderson to supply him independently with taxon occurrences. The fact that this work has not been published is certainly a regret; a solution will require all three sets of data to be properly integrated. Please Vladimir; let’s do this one last

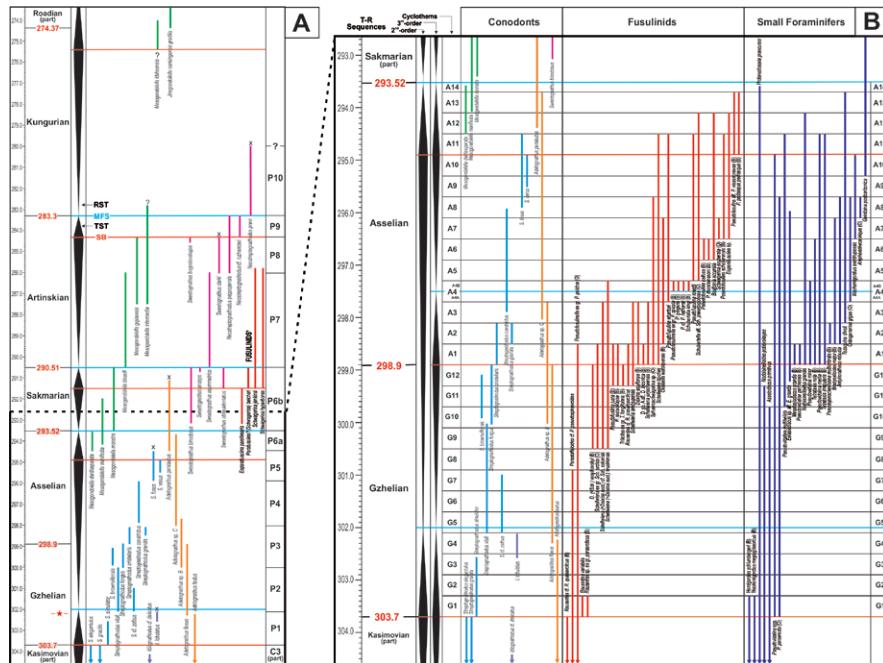


Fig. 1. This figure is modified from Beauchamp et al., 2022a. The figure shows the ranges of conodonts, fusulinids, and small foraminifers in the Gzhelian to Artinskian of the Sverdrup Basin. The only modification is the addition of some fusulinids in part A including Sakmarian occurrences from Grinnell Peninsula, Devon Island (Thorsteinsson in Harker and Thorsteinsson, 1960) and Artinskian occurrences from Blind Fiord area, but identifications are preliminary. *Parafusulina belcheri* is probably a species of *Schwagerina* (Mike Read pers.comm.2024).

paper with Mark.

In the Sverdrup Basin, Beauchamp et al. (2022b) discuss the ranges of fusulinids, small foraminifers, and conodonts and show 13.5 cyclothsems in the Asselian. Davydov (2024) discusses the fusulinid taxa to suggest that the entire interval we attribute to the Asselian is actually Sakmarian. We respectfully disagree, and offer our figure (Fig. 1) published in Beauchamp et al. (2022a). In fact one of us (BB) was very much aware that the ages provided by Daria Baranova (fusulinids), Sylvie Pinard (small foraminifers) and Charles Henderson (conodonts) were at odds with each other when he wrote (p. 237 in SEPM Special Publication 113) “Small benthic and large fusulinid foraminifers were identified at various levels throughout this sequence in sections 3, 6 and 7A. Interpreted age intervals, their diagnostic foraminifers (fusulinids and small foraminifers) and their distribution in the sections, as identified by DB, are listed in the Supplementary Material (Biostratigraphic Report). For the most part, these age interpretations are based on comparisons with decades-old biostratigraphic reports from Canada (Nilsson, 1992, 1994a; Henderson et al., 1995; Pinard and Mamet 1998), USA (Petocz, 1970), Greenland (Nilsson, 1994b; Davydov et al., 2001) and Russia (Davydov, 1986; Nikolaev et al., 1992). Based strictly on these comparisons, the thick portion of the Nansen and Hare Fiord formations studied here in the OFD would be interpreted to range from the late Gzhelian to the late Sakmarian, which is the traditional view of the age-range of the upper part of these units based on fusulinids (Harker and Thorsteinsson 1960; Nassichuk and Wilde, 1977; Lin et al., 1994), ammonoids (Nassichuk et al., 1965; Nassichuk, 1975), colonial rugose corals (Beauchamp et al., 1998; Fedorowski et al., 2007), small foraminifers (Beauchamp et al. 1998; Pinard and Mamet 1998) and, until recently, conodonts as well (Henderson 1988; Beauchamp et al. 1989b; 1998). However, the age assigned to various conodont zones in the Arctic and around the world has been reassessed in recent years in concert with the ongoing revision of the Permian time scale (Henderson 2018), and establishment of GSSP for both the base of the Asselian (Davydov et al., 1998) and Sakmarian (Chernykh et al., in press). In the wake of these recent advances in bio- and chronostratigraphic concepts, especially the “shrinking” of the Sakmarian Stage which now represents little more than 3 Myr of Earth history, the upper part of the Nansen Formation (and correlative Canyon Fiord, Belcher Channel and Tanquary formations) considered Sakmarian more than a decade ago are now in fact Asselian in age.”

Cyclothem A1 includes taxa that Davydov (2024) says are mixed with ranges from lower Asselian to upper Tastubian and concludes it is most likely lower Tastubian. He attributes assemblages in cyclothsems A4-A7 as upper Tastubian (lower Sakmarian sensu stricto by GSSP) by correlating the taxa *Schwagerina whartoni* and *Leeina callosa* among others. The occurrences of *S. whartoni* in the Blind Fiord area of Ellesmere Island (where we did our PhDs) were correlated by Nassichuk and Wilde (1977) as Asselian strictly based upon fusulinids; in fact, much of this interval was later correlated as Kasimovian and Gzhelian by Henderson et al. (1995). We also correlate part of this interval as Asselian (see Beauchamp et al., 2022a) because it includes the middle Asselian *Streptognathodus constrictus*

conodont zone. In addition, Nassichuk and Wilde (1977) also indicated that *Eoparafusulina paralinearis* was missing from the Blind Fiord area. However, it does occur on Grinnell Peninsula on Devon Island (Thorsteinsson in Harker and Thorsteinsson, 1960). Sequence stratigraphy comes to the rescue to explain these disparate locations as will be discussed below. Davydov (2024) indicates that the fusulinid assemblages in cyclothsems A11-13 are characteristic of the lower Artinskian in the Urals and that they are decidedly older than the fusulinids recovered in the type section from the very top of the Belcher Channel Formation at Grinnell Peninsula – we agree with the comment on the relative age of the Grinnell fusulinids. It turns out that the upper part of the Grinnell succession is correlative with the Raanes and Great Bear Cape formations. Beauchamp and Henderson (1994) also correlated this transgressive systems tract (TST, cyclothsems A11-13) with the lower Artinskian. However, we now correlate the A11-13 interval with the uppermost Asselian (see Figure 1, modified from Beauchamp et al., 2022a). The maximum flooding surface at the top of this TST is correlated with the base-Sakmarian on the basis of occurrences of *Mesogondolella monstra* and *Sweetognathus binodosus*, but these deeper water facies lack fusulinids. This answers Vladimir’s question

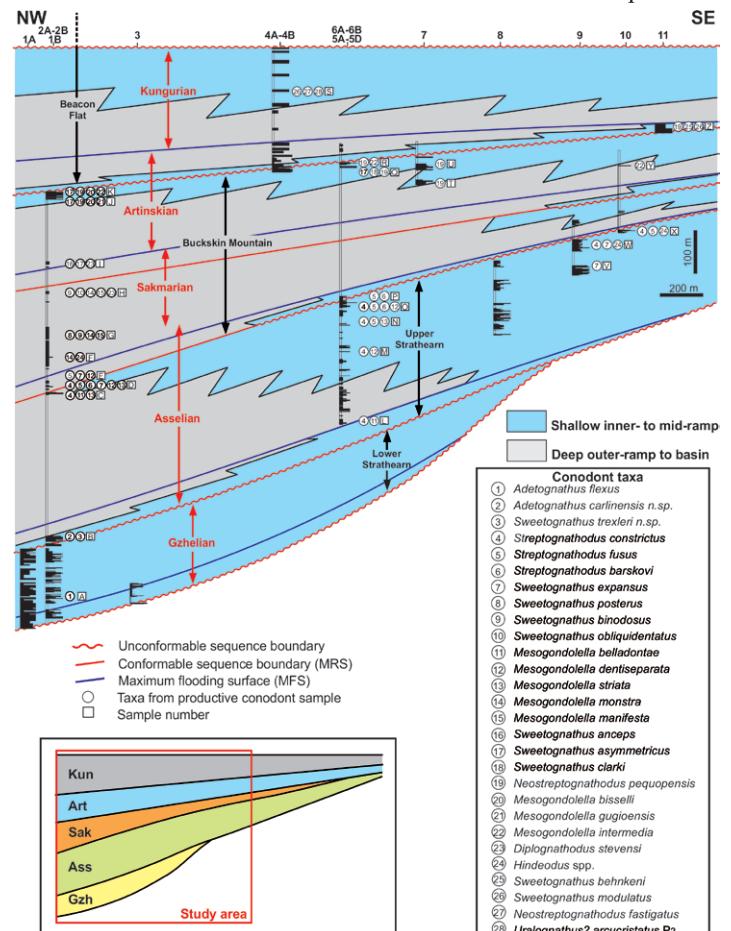


Fig. 2. This figure is modified from Beauchamp et al., 2022b. The figure shows the occurrences of key conodont species as well as the sequence stratigraphy of the Lower Permian succession in Carlin Canyon, Nevada. For comparison, the succession in the Blind Fiord area would be comparable to approximately Section 3 and the succession at Grinnell Peninsula would be comparable to section 9; the latter site includes Sakmarian inner to mid-ramp carbonate facies that are not geographically extensive.

“what is the unknown reason for not showing this photozoan facies with fusulinids and colonial corals near the Sakmarian-Artinskian boundary in Beauchamp et al. (2022a)”. We did show this in Beauchamp and Henderson (1994). To find fusulinids at this level it is necessary to investigate a much more proximal section in the Sverdrup Basin. This proximal section and its photozoan facies occurs at Grinnell Peninsula (location 69 in our 1994 paper) where Thorsteinsson in Harker and Thorsteinsson (1960) recorded faunule 2 with *Schwagerina paralinearis* n.sp. (now *Eopara fusulina*) and about 60 metres higher, faunule 3 with *Schwagerina jenkinsi* n.sp., *Schwagerina hyperborea* and *Parafusulina belcheri* n.sp. (the latter taxon is more likely a species of *Schwagerina*). We now correlate this succession with the Sakmarian with the Sakmarian-Artinskian boundary very close to the top of the exposed outcrop, based on advanced forms of *Sweetognathus binodosus* and *Sw. anceps* in association with the fusulinids (see Fig. 1) named by Thorsteinsson. Unfortunately, none of these units discussed from the Sverdrup Basin have ash beds so we have to rely on biostratigraphic correlations. Nor are there ash beds in Carlin Canyon, but conodont biostratigraphic and sequence stratigraphic correlations provide a comparable succession of zones and facies (see Fig. 2 modified from Beauchamp et al., 2022b) – note that the Sakmarian shallow inner to mid-ramp carbonates are not as geographically extensive as those associated with Asselian and Artinskian ramps. This is a reflection of the major transgression associated with the end of a major phase of the Late Paleozoic Ice Age.

So, this brings us back to the beginning of our reply. Now that we have GSSPs for the Sakmarian and Artinskian, the community has only one level to correlate for each. If necessary, the community can use terms like *sensu stricto* and *sensu lato* for a while, but this may simply confuse the process. There are many consequences of the new GSSPs and this discussion and reply demonstrate some of these. We can quickly point out a few other consequences. Look at the discussion on ammonoids for the base-Artinskian GSSP Dal’ny Tulkas section (Chernykh et al., 2023). Ruslan Kutygin indicates that an assemblage in bed 8 correlates with the Baigendzhinian at the Aktasty section, but at Dal’ny Tulkas it is considered Burtsevian. Anyone who knows the various Russian substages schemes for the Lower Permian will see the “problem”. However, it simply means that the Aktastinian is mostly Sakmarian and correlative with the upper Tastubian and Sterlitamakian whereas the Baigendzhinian correlates with the Burtsevian, Irginian, and Sarginian (the Saraninian was promoted to the Kungurian). I suspect that some of these issues may result from facies and biofacies variations associated with sequence stratigraphic successions. Davydov (2018) wrote a nice paper on the precaspian isthmus emergence and indicated that it occurred at the base of the Sakmarian, but this would now be within the late Asselian (early Tastubian *sensu lato*). Based on conodont similarities it is likely that this event occurred within the Artinskian or maybe it is an extended two-phase event. The consequences for this closure (see Davydov, 2018 and Beauchamp et al. 2022b) are significant so we really should research this topic further. As defined by GSSPs, the Asselian is now characterized by numerous glacial-eustatically driven cyclothsems (like the Gzhelian), the Sakmarian is a shorter transition interval and the Artinskian clearly postdates the main

phase of the Late Paleozoic Ice Age.

Conclusion

All of us would like a precise and stable chronostratigraphic scale. This is the aim of the GSSP process! It will not happen if the community is unwilling to accept the changes necessary to eliminate original moving targets. It will happen if we actually use our defined stage boundaries and accept the consequences that some past correlations will need revision. In so doing, all of us will have a stable and consistent temporal framework in which to compare and communicate paleogeographic and paleoclimatic events. Finally, we are confident that our current correlations are solid and as good as we can do at this time.

Selected References (others are recorded in Beauchamp et al., 2022a)

- Beauchamp, B., Gonzalez, D.C., Henderson, C.M., Baranova, D.V., Wang, H.Y. and Pelletier, E., 2022a. Late Pennsylvanian-early Permian tectonically-driven stratigraphic sequences and carbonate sedimentation along northern margin of Sverdrup Basin (Otto Fiord Depression), Arctic Canada. In Henderson, C.M., Ritter, S. and Snyder, W.S. (eds.), Late Paleozoic and Early Mesozoic Tectonostratigraphy and Biostratigraphy of western Pangea, Special Publication 113. SEPM (Society for Sedimentary Geology), Broken Arrow, Oklahoma, p. 226–254. <https://doi.org/10.2110/sepmsp.113.12>
- Beauchamp, B., Henderson, C.M., Dehari, E., Waldbott von Bassenheim, D., Elliot, S. and Calvo Gonzalez, D., 2022b. Carbonate Sedimentology and Conodont Biostratigraphy of Late Pennsylvanian-Early Permian stratigraphic sequences, Carlin Canyon, Nevada: new insights into the tectonic and oceanographic significance of an iconic succession of the Basin and Range. In Henderson, C.M., Ritter, S., Snyder, W.S. (eds.), Late Paleozoic and Early Mesozoic Tectonostratigraphy and Biostratigraphy of western Pangea, Special Publication 113: SEPM (Society for Sedimentary Geology), Broken Arrow, Oklahoma, p. 34–71. <https://doi.org/10.2110/sepmsp.113.12>
- Beauchamp, B. and Henderson, C.M., 1994. The Lower Permian Raanes, Great Bear Cape and Trappers Cove formations, Sverdrup Basin, Canadian Arctic: Stratigraphy and Conodont Zonation. Bulletin of Canadian Petroleum Geology, v. 42, n. 4, p. 562–597.
- Boardman II, D.R., Wardlaw, B.R. and Nestell, M.K., 2009. Stratigraphy and conodont biostratigraphy of the uppermost Carboniferous and Lower Permian from the North American Midcontinent. Kansas Geological Survey Bulletin, v. 255, p. 1–253.
- Chernykh, V.V., Chuvashov, B.I., Shen, S.Z., Henderson, C.M., Yuan, D.X. and Stephenson, M.H., 2020. The Global Stratotype Section and Point (GSSP) for the base- Sakmarian Stage (Cisuralian, Lower Permian). Episodes, v. 43, n. 4, 961–979.
- Chernykh, V.V., Henderson, C.M., Kutygin, R.V., Filimonova, T.V., Sungatullina, G.M., Afanasieva, M.S., Isakova, T.N., Sungatullin, R.Kh., Stephenson, M.H., Angiolini, L. and Chuvashov, B.I., 2023. Global Stratotype Section and Point (GSSP) for the base-Artinskian Stage (Lower

- Permian). *Episodes*, in press, <https://doi.org/10.18814/epiugs/2023/023015>
- Davydov, V.I., 2018. Precaspian Isthmus emergence triggered the Early Sakmarian glaciation: evidence from the Lower Permian of the Urals, Russia. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 511, p. 403–418.
- Davydov, V.I., 2024. The crisis in the global Permian correlation – Canadian Arctic-Urals case. *Permophiles*, n. 76, p. 35–41.
- Di Pasquo, M., Grader, G.W., Isaacson, P., Souza, P.A., Iannuzzi, R. and Diaz-Martinez, E., 2015. Global biostratigraphic comparison and correlation of an early Cisuralian palynoflora from Bolivia. *Historical Biology*, v. 27, n. 7, p. 868–897.
- Harker, P. and Thorsteinsson, R., 1960. Permian rocks and faunas of Grinnell Peninsula, Arctic Archipelago. Geological Survey of Canada, Memoir 309, 89 pp.
- Henderson, C. M., 2018. Permian Conodont Biostratigraphy. In Lucas, S. G. and Shen, S. Z. (eds.), *The Permian Timescale*. Geological Society, London, Special Publications, v. 450, n. 1, p. 119–142. <http://doi.org/10.1144/SP450.9>.
- Henderson, C.M. and Chernykh, V.V., 2021. To be or not to be *Sweetognathus asymmetricus*? *Permophiles*, n. 70, p. 10–13.
- Lucas, S.G., Henderson, C.M., Barrick, J.E. and Krainer, K., 2022. Conodonts and the correlation of the Lower Permian Yeso Group, New Mexico, USA. *Stratigraphy*, v. 19, n. 2, p. 77–94.
- Nassichuk, W.W. and Wilde, G.L., 1977. Permian fusulinaceans and stratigraphy at Blind Fiord, southwestern Ellesmere Island. *Geological Survey of Canada Bulletin*, v. 268, p. 1–60.
- Petryshen, W., Henderson, C.M., De Baets, K. and Jarochowska, E., 2020. Evidence of parallel evolution in the dental elements of *Sweetognathus* conodonts. *Proceedings of the Royal Society B*, v. 287, n. 1939, p. 20201922. <http://dx.doi.org/10.1098/rspb.2020.1922>
- Wardlaw, B.W., Gallegos, D.M., Chernykh, V.V. and Snyder, W.S., 2015. Early Permian conodont fauna and stratigraphy of the Garden Valley Formation, Eureka County, Nevada. *Micropaleontology*, v. 61, n. 4–5, p. 369–387.

The basal Guadalupian Series/Roadian Stage GSSP preserves the traditional Roadian Stage Concept—and is thus highly workable

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I largely agree with Charles Henderson (2024) on the great majority of his points in response to Spencer Lucas (2024) in *Permophiles* #76. However, this corresponding note begins by correcting a misimpression left by his paragraph referring to me—and then addresses some related criticisms of the GSSP that have been made by Lucas and others. Many of those criticisms rely on old lithostratigraphic misconceptions and the resulting biostratigraphic conflicts resulting from them (see Lambert et al., 2000).

On page 12 in the upper right-hand paragraph, Henderson

(2024) states “Lance Lambert (for the 1999 proposal) in consultation with Bruce Wardlaw arbitrarily chose a structure on the lower surface keel, but upper surface serration in lateral view may be more characteristic. This needs to be better documented.” My response: On page 4 of *Permophiles* #34 in the right-hand column, we very briefly describe the evolutionary transition using multiple characters—the characters of platform margin serration (visible in upper and side views), platform shape (visible in upper and lower views), keel and attachment surface (lower view), denticle and cusp expression (upper and side views), and furrow expression (upper view; Glenister et al., 1999). Characters of the lower surface were (and still are) seldom considered in species-level conodont taxonomy, so that may explain why Charles only remembered the keel when writing Henderson (2024).

Note that the brief descriptions in Glenister et al. (1999) were derived from more extensive descriptions of upper, side, and lower views written and published previously, especially Lambert et al. (2000) [written first] and Lambert and Wardlaw (1992). Lambert et al. (2000) included a plate organized with the ancestor at bottom, transitional forms in the middle, and descendant at the top. Upper, side, and lower views of all three are illustrated in the plate (see Figs. 1A-C). The photographic images were taken through a traditional microscope on purpose: Although not as sharply focused as SEM images would have been, the characters are not “flattened” (distorted) by SEM imagery. You see what you would see as you examine specimens in any reflected-light microscope.

The point in the transition I recommended and was adopted by the Guadalupian Task Group is illustrated on the plate (note especially images 11, 13, and 18 for upper, lower, and side views respectively). This is a point roughly mid-transition where the serrations are present in adult specimens, but are not fully developed (shallow, rather than deeply cut—see both upper and side views). I recommended this point in the transition not only because the platform margins are intermediate between smooth and serrated, but also because it is the only level where the platform margins commonly extend to surround the ventral (anterior) platform—in other words, the “free blade” disappears in adult specimens. That character is distinct enough that non-conodont specialists can easily recognize it among the transitional forms and thus recognize the level of the GSSP.

Unbroken specimens were chosen whenever possible for the plate because detailed morphology for the ancestor, transitional forms, and descendant was important for comparison. Only the triangular cusp complex, a morphology in ancestral populations, did not have an unbroken example. Lambert et al. (2000) was supposed to be the first presentation of this data back in the early 1990s, but publication of the Smithsonian volume was delayed by almost a decade. A criticism has been that specimens have not been illustrated from the GSSP section. The purpose in Lambert et al. (2000) was to introduce and demonstrate the transition, not illustrate specimens from any particular section. The genus *Jinogondolella* evolved across the entire Permian Basin, not just at one single section—so the specimens used are all valid documentation of the evolutionary event. I recognize that the eventual formal *Episodes* paper should include specimens from the GSSP section, but those who say that the conodonts used for

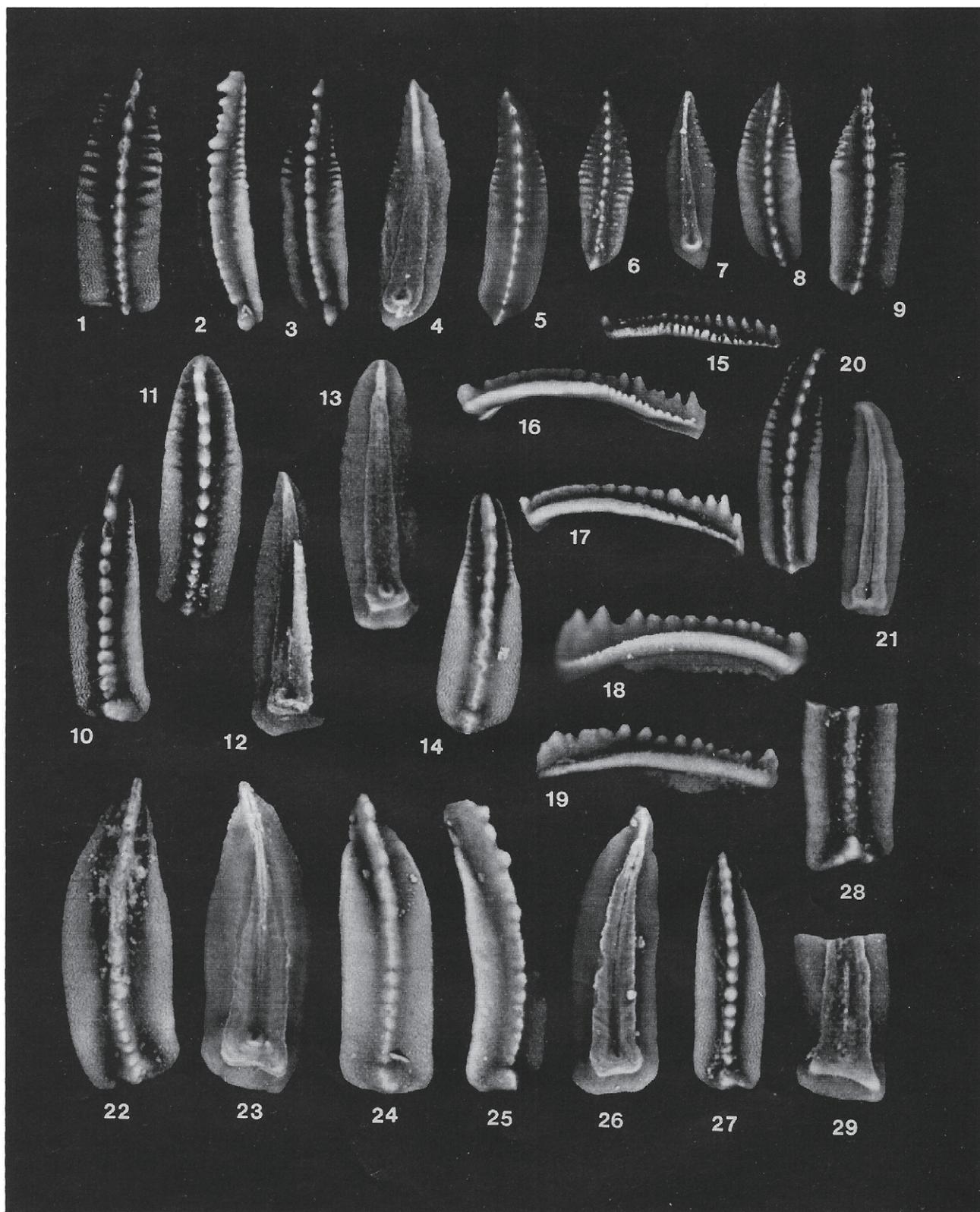


Fig. 1A . A copy of Plate 8-4 from Lambert et al. (2000), illustrating the conodont transition from *Mesogondolella* to *Jinogondolella*.

PLATE 8-4

Conodonts from the basal Guadalupian and the Roadian–Wordian boundary strata, West Texas. (All figures are of Pa elements at $\times 50$ magnification.)

FIGURES 1–9, 15, 16.—*Mesogondolella nankingensis* (Ching, 1960): 1, upper view, quadrate form, hypotype, SUI 64521; 2–4, 16, upper oblique, upper, lower, and right lateral views, specimen with atypically large rounded cusp, hypotype, SUI 64522; 5, upper view, hypotype, SUI 64523; 6, 7, 15, upper, lower, and right lateral views, subadult with abundant serrations, hypotype, SUI 64524; 8, upper view, subadult of earliest *M. nankingensis* s.s., exhibiting several characters of the transitional form, hypotype, SUI 64525; 9, upper view, quadrate form less serrated than Figure 1, hypotype, SUI 64526. 1–5, 9, 16, Pipeline Shale Member type section, Brushy Canyon Formation, Loc. 1 (type stratum of *M. nankingensis*); 6, 7, 15, Williams Ranch Member, Cutoff Formation, Loc. 3; 8, Road Canyon Formation type section, Loc. 7. (Reduced to 84% of original for publication.)

FIGURES 10–14, 17, 18, 20, 21.—Forms transitional between *M. idahoensis* and *M. nankingensis*: 10, 12, 18, upper, lower, and left lateral views, transitional form with primarily *M. idahoensis*-like characters, hypotype, SUI 64527; 11, 13, upper and lower views, form with approximately equal mix of ancestral and descendant characters, hypotype, SUI 64528; 14, upper view, specimen with incipient serrations but otherwise more reminiscent of *M. idahoensis*, hypotype, SUI 64529; 17, 20, 21, right lateral, upper, and lower views, transitional form dominated by many *M. nankingensis*-like characters, hypotype, SUI 64530. 10–13, 18, El Centro Member, Cutoff Formation, Loc. 5; 14, 17, 20, 21, El Centro Member, Cutoff Formation, Loc. 6. (Reduced to 84% of original for publication.)

FIGURES 19, 22–29.—*Mesogondolella idahoensis* (Younquist, Hawley, and Miller, 1951): 19, 27, left lateral and upper views, note posterior termination of adcarinal furrows, hypotype, SUI 64531; 22, 23, upper and lower views, very large specimen with characteristic lower view, hypotype, SUI 64532; 24–26, upper, upper oblique, and lower views, very large specimen with characteristic carina, hypotype, SUI 64533; 28, 29, upper and lower views, note triangular cusp complex, hypotype, SUI 64534. 19, 27–29, Leonardian lectostratotype, Loc. 8; 22–26, Victorio Peak Limestone, Loc. 9. (Reduced to 84% of original for publication.)

Fig. 1B. A copy of the original caption to Plate 8-4 from Lambert et al. (2000).

boundary recognition have never been figured are incorrect.

While on the topic of the Permian Basin, it is important to note that Harris et al. (2000) should be read along with Lambert et al. (2000). Harris et al. (2000) emphasized the physical stratigraphic parameters that match the Road Canyon Formation in the Glass Mountains with the Cutoff Formation in the Guadalupe Mountains (and also the Delaware and Apache mountains). Lambert et al. (2000) emphasized the biostratigraphic correlations between the Road Canyon and Cutoff, and corrected previous entrenched lithostratigraphic misconceptions that had complicated faunal comparisons between the different mountain ranges. The primary conclusions of Lambert et al. (2000) were preliminarily presented as a talk at the Guadalupian Symposium (Lambert et al., 1991). Many of the points made there (like the corrections to lithostratigraphic correlations) clarified several issues and swiftly began to be used by workers in west Texas—which may be why the Smithsonian papers did not get the attention they should have once finally published.

The Road Canyon and its fauna (especially ammonoids) provide the original concept of the Roadian Stage. The near perfect equivalency of depositional conditions and biostratigraphic zonation at opposite ends of the Delaware Basin would have been abundantly clear had the Smithsonian publication not been delayed for so long. But arguments based on the entrenched misconceptions continued to be made though the intervening years, some arguments developing their own momentum with authors ignoring the Smithsonian papers once they were finally published. Spencer Lucas has never cited them even though they were seminal to development of the Guadalupian/Roadian GSSP concept.

A brief summary of points from those two papers that are pertinent to Lucas's (2024) arguments: Both the Cutoff Formation as expressed along the Western Escarpment of the Guadalupe Mountains and the Road Canyon Formation at its type section in the Glass Mountains represent slope depositional environments that begin with transgressive deposits and megabreccia-filled channels cut into the preceding strata (Bone Spring and Cathedral Mountain formations, respectively). Mostly aggradational slope

Appendix 8-1: Locality Register for Figured Specimens

- Pipeline Shale Member type section, Brushy Canyon Formation ($31^{\circ}50'5''N$, $104^{\circ}50'5''W$). 3.5 mi (5.8 km) SSW of El Capitan, 0.4 mi (0.7 km) along El Paso Gas Company right-of-way pipeline road, west of junction with U.S. 62/180, Culberson County, Texas. Samples from basal phosphatic interval with carbonate concretions containing abundant ammonoids. Private ranch, permission to collect required.
- Williams Ranch Member, Cutoff Formation ($31^{\circ}50'2''N$, $104^{\circ}50'6''W$). Top beds of Cutoff Formation, containing abundant large allochthonous clasts; exposed primarily by road grading and pipeline construction (see Locality 1). Private ranch, permission to collect required.
- Williams Ranch Member, Cutoff Formation ($31^{\circ}50'3''N$, $104^{\circ}50'3''W$). East wall of ravine S of Pipeline Shale Member type section (see Locality 1). Sample from uppermost resistant bed without allochthonous clasts. Private ranch, permission to collect required.
- Williams Ranch Member, Cutoff Formation ($31^{\circ}49'7''N$, $104^{\circ}49'42''W$). Quarry along right-of-way on NW side of U.S. 62/180, 1.8 mi (3 km) NE of junction with Hwy 54, Culberson County, Texas.
- El Centro Member, Cutoff Formation ($31^{\circ}52'58''N$, $104^{\circ}52'48''W$). Along westward facing scarp, south wall of Bone Canyon. Sample from upper-middle of carbonate unit as exposed. Guadalupe Mountains National Park, permission to collect required.
- El Centro Member, Cutoff Formation ($31^{\circ}53'25''N$, $104^{\circ}52'33''W$). South wall of southern branch of Shumard Canyon, directly over channel filled with Shumard Member. Sample from basal bed of middle carbonate unit. Guadalupe Mountains National Park, permission to collect required.
- Road Canyon Formation type section ($30^{\circ}20'53''N$, $103^{\circ}15'2''W$). SE face of spur 0.5 mi (0.8 km) SE of Peak 5779, 2.4 mi (4 km) due N of Skinner Ranch, Altuda quadrangle, Brewster County, Texas. (Description from Cooper and Grant, 1964.) Samples from 10 ft (3 m) above top of drape beds overlying uppermost megabreccia (within unit 8 of Cys, 1981). Private ranch, permission to collect required.
- Leonardian Lectostratotype, Cathedral Mountain Formation ($30^{\circ}20'52''N$, $103^{\circ}15'2''W$). Sample from uppermost bed underlying large Road Canyon megabreccia block that is sunk into the top of the Cathedral Mountain Formation, just E of Cys (1981) section (see Locality 7). Private ranch, permission to collect required.
- Victorio Peak Limestone ($31^{\circ}11'42''N$, $104^{\circ}36'1''W$). Hills W of Old Jones Ranch house and Ranch Road 2185, western Apache Mountains, Culberson County, Texas. Sample from uppermost bed of Victorio Peak Limestone, in gully just S of Wood's (1968) Measured Section I. Private ranch, permission to collect required.
- USNM Loc. 732z. Road Canyon Formation ($30^{\circ}14'24''N$, $103^{\circ}27'0''W$). 1.36 mi (2.3 km) $N50^{\circ}W$ of Old Payne Ranch site, 1.2 mi (2 km) $N2^{\circ}W$ of hill 4806, Monument Spring quadrangle. (Description from Cooper and Grant, 1977.) Private ranch, permission to collect required.
- AMNH Loc. 503. Road Canyon Formation ($30^{\circ}23'28''N$, $103^{\circ}8'47''W$). Near top of slope 3.5 mi (5.8 km) $S75^{\circ}W$ of Old Word Ranch, 1.15 mi (1.9 km) $S37^{\circ}E$ of hill 5507, and 0.65 mi (1.1 km) SW of road fork to Appel Ranch house, Hess Canyon quadrangle. (Description from Cooper and Grant, 1972.) Private ranch, permission to collect required.

Fig. 1C. A copy of Appendix 8-1 from Lambert et al. (2000) for locality information cited in the original plate caption.

sedimentation is then recorded through conditions of sea-level rise in both ranges. Just below the third-order maximum flooding units, the transition from *Mesogondolella* to *Jinogondolella* is preserved. That results in the Guadalupian/Roadian GSSP having a distinct eustatic (physical stratigraphic) signal that can be correlated worldwide in many different lithofacies, including those without conodonts. The eustatic signal is also expressed distinctively in electric well logs in the subsurface. That well log signal has been confirmed by conodonts from subsurface cores of logged wells in the Delaware Basin (see Fig. 2 and Lambert, 2000).

The significance of the preceding paragraph that some workers miss is that the original basis of the Roadian concept is not changed by establishing the GSSP in the Guadalupe Mountains. The Cutoff and Road Canyon formations have synchronous bases that record renewed sedimentation over an erosional or discontinuity surface. Lambert et al. (2000) specifically addressed the ammonoid and fusulinid correlations between the two mountain ranges and showed that—by correcting the old

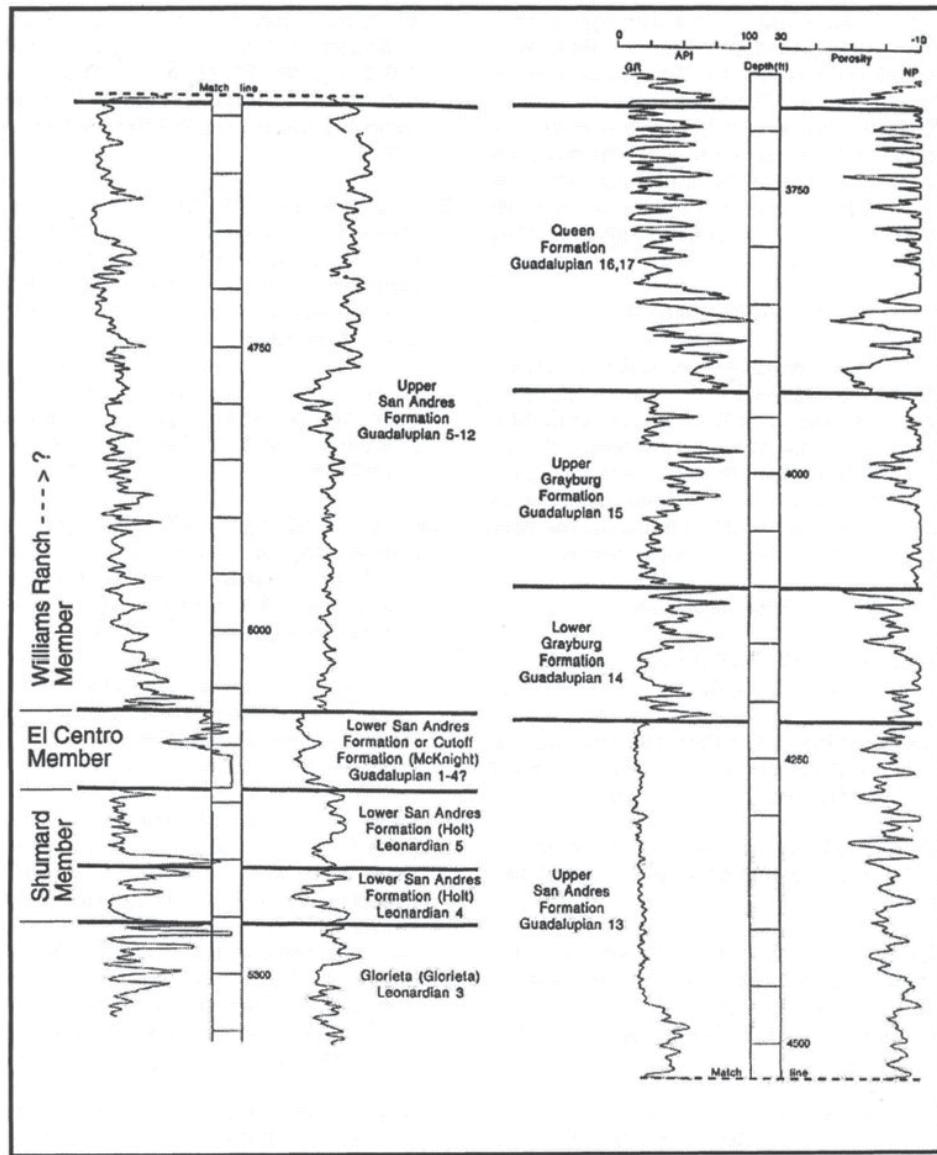


Figure 3.—Wire-line log from North Cowden field, showing typical log response and unit stratigraphy around the basal Guadalupian boundary. Informal subsurface names are given in parentheses. Correlative Cutoff Formation outcrop members are interpreted to the left. Amoco Producing Company, Frank Cowden R/A A No. 47, Andrews County, Texas (KB=3125 ft). After Kerans & Ruppel (1994).

Fig. 2. A copy of Figure 3 from Lambert (2000), illustrating the well log character of the Cutoff equivalent units in the subsurface of the Delaware Basin. The depositional environment is distal shelf towards the shelf margin. The distinctive log “kick” or deflection in the McKnight shale that lines up between the words El Centro and Member (Cutoff equivalents) corresponds with the GSSP based on conodonts recovered from core of a nearby well with a similar well log. See Hurd et al. (2018) for more recent and more detailed surface to subsurface correlations.

and entrenched lithostratigraphic miscorrelations—the conodont, ammonoid, and fusulinid biostratigraphies are all congruent and distinctive for the Roadian Stage in West Texas. Criticisms that the traditional ammonoid biostratigraphy is somehow disrupted by the GSSP level (e.g., Leonova, 2018, among numerous others) are based on uncritically promulgating the miscorrelation of Spinoza et al. (1975), whose road quarry ammonoid locality is actually from the top member of the Cutoff Formation (Lambert et al., 2000)—not from the Bone Spring Formation*.

The Cutoff Formation of the Guadalupe Mountains was selected for the GSSP because it is protected in a national park where international scientific access is available. Although the

Road Canyon Formation has a higher diversity of fossil groups in many measured sections, it is located on private ranches where access cannot be guaranteed over the long term. The extensive, diverse Road Canyon fossil collections of Cooper and Grant are available for study at the Smithsonian (see especially Cooper and Grant, 1977, as well as the other five volumes of the series), as are other collections from the Glass Mountains. A huge number of fossil collections from the Cutoff Formation are similarly available. The Newell et al. (1953) collections are available at the American Museum of Natural History, and there are large collections at the Smithsonian, the University of Iowa Geology Repository, and the New Mexico Museum of Natural History—

among others. But with a collecting permit you can make your own collections from outcrops in Guadalupe Mountains National Park.

It is appropriate here to also address criticisms regarding serrated conodonts that have recently been recovered significantly below the GSSP level. Also addressed by Henderson (2024), I just wish to elaborate a bit more. Serrations are a character that is not terribly uncommon in gondolellid conodonts. Serrations are generally restricted to juvenile specimens in most *Mesogondolella* below the El Centro Member of the Cutoff Formation. The evolutionary transition selected to mark the Guadalupian/Roadian GSSP took place through a paedomorphocline that led to a clade of predominantly serrated *Jinogondolella* adults. But serrated margins are not the only character that distinguishes the two genera. Lambert et al. (2006, 2007) presented additional multielement differences that characterize *Jinogondolella* (features of other elements in the apparatus). A serrated *Mesogondolella* species lower in the section, if it is confirmed in adults, does not affect the transitional paedomorphocline of the GSSP nor the species that comprise *Jinogondolella*.

Following that topic, another (relatively more minor) issue is the recent push to shift the GSSP definition up-section a few meters to the first occurrence of “classical” *Jinogondolella nankingensis*. In my opinion those suggestions are misguided. If you read the original papers on the philosophy behind “golden spikes”, the purpose of a complete morphological transition is to demonstrate that the section has no depositional gaps. Thus, when a GSSP is selected within the transition (not at the top of one) it means that at any other section where the defining species is first recovered, you are demonstrably in that chronostratigraphic unit—in the case of *Jinogondolella nankingensis*, the Guadalupian Series and the Roadian Stage. Shifting the GSSP up-section to a sample with the “classic” characters risks imprecision if a future sample just below the level chosen by one group of workers is considered by other workers to have the “classic” characters.

Finally, a brief historical comment on another issue brought up by Lucas (2024) as well as others. An *Episodes* manuscript was started shortly after Glenister et al. (1999) was published, first with Brian Glenister, then with Bruce Wardlaw as lead author. It was submitted to *Episodes* in 2006. The reviewers pointed out that taxa other than conodonts and the non-paleontological data both needed to be described in significantly more detail. Bruce never got around to making those edits, but he did not want to relinquish the manuscript to me or any of the other co-authors because he fully intended to draft them himself. By the time of his untimely death, the serious problems with the Wordian GSSP became known. Also by then, I was working with Shen Shuzhong, Charles Henderson, and a large contingent of others to gather more data on the Guadalupian GSSPs (e.g., Shen et al., 2020; Wu et al., 2020; Yuan et al., 2021; Shen et al., 2022).

Henderson (2024) addressed the Lucas (2024) charges of politics quite well. As my own editorial comment, I think that politics have much more to do with the current efforts to move the ratified Guadalupian/Roadian GSSP than was ever involved in the original research to establish it. Sadly, we already had a new *Episodes* manuscript roughly three-quarters completed

before the recent disruptions interfered with writing it. Yes, there are serious problems with the Wordian GSSP, although the possible resolutions suggested in Henderson (2024) would be the quickest way to address those problems. However, the Guadalupian/Roadian GSSP does not have such problems, it is merely (willfully?) misunderstood. By preserving the traditional Roadian concept, it is stable, practical—and with the complete paedomorphocline preserved—precise.

Acknowledgements

My appreciation is extended to Charles Henderson for his beneficial review of this contribution.

References

- Cooper, G.A. and Grant, R.E., 1977. Permian brachiopods of west Texas, VI. Smithsonian Contributions to Paleobiology, v. 32, p. 3161–3370.
- Glenister, B.F., Boyd, D.W., Furnish, W.M., Grant, R.E., Harris, M.T., Kozur, H., Lambert, L.L., Nassichuk, W.W., Newell, N.D., Pray, L.C., Spinoza, C., Wardlaw, B.R., Wilde, G.L. and Yancey, T.E., 1992. The Guadalupian: Proposed international standard for a Middle Permian Series. International Geology Review, v. 34, p. 857–888.
- Glenister, B.F., Wardlaw, B.R., Lambert, L.L., Spinoza, C., Bowring, S.A., Erwin, D.H., Menning, M. and Wilde, G.L., 1999. Proposal of Guadalupian and component Roadian, Wordian, and Capitanian stages as international standards for the Middle Permian Series. Permophiles, n. 34, p. 3–11.
- Harris, M.T., Lehrmann, D.J. and Lambert, L.L., 2000. Comparison of the depositional environments and physical stratigraphy of the Cutoff Formation (Guadalupe Mountains) and Road Canyon Formation (Glass Mountains): Lowermost Guadalupian (Permian) of west Texas. In Wardlaw, B.R., Grant, R.E., and Rohr, D.M. (eds.), The Guadalupian Symposium. Smithsonian Contributions to the Earth Sciences v. 32, p. 127–152.
- Henderson, C.M., 2024. The Permian Guadalupian stages: how collaborative science and conodonts can produce a workable chronostratigraphy. Permophiles, n. 76, p. 11–13.
- Hurd, G.S., Kerans, C., Frost, E.L., Simo, J.A. and Janson, X., 2018. Sediment gravity-flow deposits and three-dimensional stratigraphic architectures of the linked Cutoff, upper Bone Spring, and upper Avalon system, Delaware Basin. AAPG Bulletin, v. 102, p. 1703–1737.
- Kerans, C. and Ruppel, S.C., 1994. San Andres sequence framework, Guadalupe Mountains: Implications for San Andres type section and subsurface reservoirs. In Garber, R.A. and Keller, D.R. (eds.), Field Guide to the Paleozoic Section of the San Andres Mountains. Permian Basin Section-SEPM Publication, 94–35, p. 105–115.
- Lambert, L.L., 2000. The Guadalupian GSSP The world standard Middle Permian Series Guadalupe Mountains National Park. In Crow, C.J. and Bell, G.L.Jr. (eds.), Guadalupian Deposition in Sabkha, Shelf, Reef, and Basin Environments, Guadalupe Mountains, Texas and New Mexico. Field Trip Guidebook, AAPG EAGE (American Association of Petroleum Geologists-European Association of Geoscientists

- and Engineers) International Research Conference, El Paso, Texas. p. 57–71.
- Lambert, L.L. and Wardlaw, B.R., 1992. Morphological transition from *Mesogondolella idahoensis* to *M. serrata*: Basal Guadalupian definition. Appendix II, p. 876–880. In Glenister et al., 1992. The Guadalupian: Proposed international standard for a Middle Permian Series. International Geology Review, v. 34, p. 857–888.
- Lambert, L.L., Lehrmann, D.J. and Harris, M.T., 1991. Faunal correlation of the Road Canyon and Cutoff formations, west Texas, and its bearing on the Leonardian/Guadalupian Boundary. In Wardlaw, B.R., Grant, R.E. and Rohr, D.M. (eds.), Proceedings of the Guadalupian Symposium, [Sul Ross State University, Alpine, Texas.], p. 7.
- Lambert, L.L., Lehrmann, D.J. and Harris, M.T., 2000. Correlation of the Road Canyon and Cutoff Formations, west Texas, and its relevance to establishing an international Middle Permian (Guadalupian) Series. In Wardlaw, B.R., Grant, R.E. and Rohr, D.M. (eds.), The Guadalupian Symposium. Smithsonian Contributions to the Earth Sciences, v. 32, p. 153–183.
- Lambert, L.L., Wardlaw, B.R. and Henderson, C.M., 2006. Multielement definition of *Jinogondolella* Mei and Wardlaw. Permophiles, v. 48, p. 20–22.
- Lambert, L.L., Wardlaw, B.R. and Henderson, C.M., 2007. *Mesogondolella* and *Jinogondolella* (Conodonts): Multielement definition of the taxa that bracket the basal Guadalupian (Middle Permian Series) GSSP. Palaeoworld, v. 16, p. 208–221.
- Leonova, T.B., 2018. Permian ammonoid biostratigraphy. In Lucas, S.G. and Shen, S.Z. (eds.), The Permian Timescale. Geological Society of London, Special Publication, v. 450, p. 185–203.
- Lucas, S.G., 2023. The Guadalupian Series and the Permian timescale. New Mexico Geological Society, 73rd Fall Field Trip Conference Guidebook, p. 82–88.
- Lucas, S.G., 2024. The Permian Guadalupian stages: how politics and conodonts produced an unworkable chronostratigraphy. Permophiles, n. 76, p. 9–11.
- Newell, N.D., Rigby, J.K., Fischer, A.G., Whiteman, A.J., Hickox, J.E. and Bradley, J.S., 1953. The Permian Reef Complex of the Guadalupe Mountains region, Texas and New Mexico: A study in paleoecology. W.H. Freeman and Company, San Francisco, 236pp.
- Shen, S.Z., Yuan, D.X., Henderson, C. M., Wu, Q., Zhang, Y.C., Zhang, H., Mu, L., Ramezani, J., Wang, X.D., Lambert, L. L., Erwin, D.H., Hearst, J.M., Xiang, L., Chen, B., Fan, J.X., Wang, Y., Wang, W.Q., Qi, Y.P., Chen, J., Qie, W.K. and Wang, T.T., 2020. Progress, problems and prospects: An overview of the Guadalupian Series of South China and North America. Earth Science Reviews, v. 211, p.103412.
- Shen, S.Z., Yuan, D.X., Henderson, C.M., Lambert, L.L., Zhang, Y.C., Erwin, D.H., Ramezani, J., Wang, X.D., Zhang, H., Wu, Q., Wang, W.Q., Hearst, J.M., Chen, J., Wang, Y., Qie, W.K., Qi, Y.P. and Wardlaw, B.R., 2022. The Global Stratotype Section and Point (GSSP) for the base of the Capitanian Stage (Guadalupian, Middle Permian). Episodes, v. 45, p. 309–331.
- Spinoza, C., Furnish, W.M. and Glenister, B.F., 1975. The Xenodiscidae, Permian ceratitoid ammonoids. Journal of Paleontology, v. 49, p. 239–283.
- Walker, W., Jobe, Z.R., Sarg, J.F., and Wood, L., 2021. Progradational slope architecture and sediment distribution in outcrops of the mixed carbonate-siliciclastic Bone Spring Formation, Permian Basin, west Texas. Geosphere, v. 17, p. 1268–1293.
- Wu, Q., Ramezani, J., Zhang, H., Yuan, D.X., Erwin, D. H., Henderson, C.M., Lambert, L.L., Zhang, Y.C. and Shen, S.Z., 2020. High-precision U-Pb zircon age constraints on the Guadalupian in West Texas, USA. Palaeogeography, Palaeoclimatology, Palaeoecology. v. 548, p.109668.
- Yuan, D.X., Shen, S.Z., Henderson, C.M., Lambert, L.L., Hearst, J.M., Zhang, Y.C., Chen, J., Qie, W.K., Zhang, H., Wang, X.D., Qi, Y.P. and Wu, Q., 2021. Reinvestigation of the Wordian-base GSSP section, West Texas, USA. Newsletters on Stratigraphy, v. 54, p. 301–315.

*Contrary to what Lucas (2024) asserts, Lambert et al. (2000) specifically dealt with the ammonoids and fusulinids. The paper includes two plates of ammonoids that illustrate the most distinctive Roadian taxa. It also includes tables that show which ammonoids are recovered from the formations concerned, highlighting that the Cutoff and Pipeline faunas are different. The Pipeline Member is the lowest unit of the Brushy Canyon Formation. The Pipeline ammonoids can be used to mark what has traditionally been considered the base of the Wordian Stage because they correlate with the very topmost beds of the Road Canyon Formation immediately beneath the base of the Word Formation in the Glass Mountains.

Fig.1 of Lucas (2024) has many errors and feeds miscorrelation. Only considering the strata discussed here, note that (unlike shown) the Cutoff Formation is fully developed across the basin, as demonstrated by several outcrops in the Delaware as well as the Guadalupe mountains. The Brushy Canyon Formation is not equivalent to the Cutoff as shown in the Lucas (2023, 2024) figure, but overlies it as described above. Referring to the right-hand side of the Lucas (2023, 2024) figure, the Brushy Canyon Formation is predominantly equivalent to the Word Formation in the Glass Mountains, not the Road Canyon Formation.

Possibly Spencer Lucas is mixing subsurface terminology with outcrop terminology. If so, it is misleading without a statement of that approach. More likely he is just confused. Petroleum industry subsurface terms used for well log correlation often do not match outcrop terminology. Cutoff-equivalent strata recorded on electric logs from the basin have traditionally been lumped with the Bone Spring because both are predominantly carbonate units that underly the extremely thick siliciclastic deposits of the Delaware Mountain Group (Brushy Canyon Formation at the base). In traditional industry terms, the Cutoff units are commonly referred instead to the “First Bone Spring Lime” or some similar derivative term that can vary by company. With the development of fracking technologies, part of the organic-rich Cutoff in the subsurface has become the very productive Avalon Shale Play (e.g., Hurd et al., 2018; Walker et al., 2021).

The Kungurian GSSP candidate at Rockland (Nevada) revisited

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From May 17 to May 25, 2024, Lucia Angiolini (University of Milano), Charles Henderson (University of Calgary), Mike Read (Stephen F. Austin State University), and Andrea Zanchi (University of Milano-Bicocca), visited the Cisuralian successions at Carlin Canyon (near Carlin, Nevada) and Rockland (near Wells, Nevada).

The Rockland section (40.77904°N and 114.60604°W) is the only candidate for the base Kungurian GSSP at 1813.5 metres from the base of the section (see RC11-11.6 in fig. 2 of Henderson et al., 2012), marked by the FAD of *Neostreptognathodus pnevi*. The Lower Permian Pequop Formation is here well exposed with continuous Sakmarian to Kungurian outer ramp carbonate facies, and an expanded base-Kungurian boundary interval. The Permian part of the section is approximately 1350 metres thick and the GSSP level is 580 m above the base of the Permian (Fig. 1), which sits unconformably upon Moscovian (Middle Pennsylvanian) carbonate units. The hike to Rockland offers a few challenges (Fig. 2), but the view at the top, of the Basin and Range province of Nevada, is well worth the effort.

The Rockland Section has good conodont biostratigraphy and now has strontium (Sr) isotope ratios based on whole rock and conodonts (Fig. 1). Conodonts are well-studied within the section (Henderson et al., 2012; Angiolini et al., 2023). Strontium isotope data from whole rock were produced in Tierney (2010) and more recently additional analyses have been performed by Kate Tierney (University of Iowa), supported by SPS funds to complete the curve through the GSSP level. Additional Sr-isotope ratios from whole rock and from conodonts are now available through the MSc thesis of Luke Bratton (University of Calgary), which he defended in July 2024. The Sr-isotopic values fit the “global” Sr-curve of McArthur (2020) for the Sakmarian and early Artinskian, but then deviate to more radiogenic values. These discrepancies are interpreted in Bratton (2024) and will be discussed in the upcoming proposal. The main goal of visiting the section during May 2024 was to sample for fusulinids within the

boundary interval (Fig. 3). During the fieldwork, one of us (M.R.) was able to collect numerous and well-preserved fusulinids from several beds of the section both from below and above the GSSP candidate level. These samples are in preparation now and preliminary identifications are being currently conducted. When completed, a GSSP proposal will be prepared for discussion in the next issue of *Permophiles* in January 2025 that will include Sr-isotopes as well as conodont and fusulinid biostratigraphy.

During May 2024, we collected lithologic samples and thin sections have already been prepared. The carbonate sedimentology of the boundary interval will be described by Benoit Beauchamp and included in the GSSP proposal. We were also able to find a few brachiopod shells from below and up to the GSSP level. The shell microstructure has been studied with an SEM and appears well-preserved. Oxygen, carbon and strontium analyses are in progress and they will provide further data for the GSSP proposal to assess the trend of the Sr-curve for this time interval. This recent work has allowed us to overcome two limitations of the Rockland section as a GSSP candidate including additional biostratigraphic work and actual Sr-isotopic ratios to replace the extrapolation shown in Henderson et al. (2012).

We also spent three days in Carlin Canyon to continue to investigate the potential of the upper Asselian to upper Artinskian succession in this area to serve as a Standard Auxiliary Boundary Stratotype (SABS) candidate for the base-Sakmarian and base-Artinskian. We sampled the Upper Strathearn (Figs. 4, 5), Buckskin Mountain and Beacon Flat formations, with a focus on sampling for fusulinids and brachiopods. Extensive conodont work is already complete (Beauchamp et al., 2022) and some Sr-isotope data have also been produced (Bratton, 2024). Finally, a structural analysis was also completed in the area adding to work done in the 2022 site visit (Angiolini et al., 2023). This work will help unravel the subsequent tectonic events that affected the area.

During the trip, we also met with Cheryl Miller (Supervisory Park Ranger, California Trail Interpretive Center, Bureau of Land Management, Elko) and Glenn Reynolds (Park Ranger Interpretive Lead, CTIC, BLM) to tell them of our plans for a GSSP at Rockland and a SABS at Carlin Canyon. We had a very enthusiastic discussion regarding access, site protection and signage. Both sites are on BLM land and freely accessible.

References

- Angiolini, L., Beauchamp, B., Bratton, L., Fraser, B., Henderson, C., Synder, W., and Zanchi, A., 2023. The once and future quest: the Kungurian GSSP candidate at Rockland Section and SABS at Carlin Canyon, Nevada. *Permophiles*, n. 74, p. 37–41.
- Beauchamp, B., Henderson, C.M., Dehari, E., Waldbott von Bassenheim, D., Elliot, S. and Calvo Gonzalez, D., 2022. Carbonate Sedimentology and Conodont Biostratigraphy of Late Pennsylvanian-Early Permian stratigraphic sequences, Carlin Canyon, Nevada: new insights into the tectonic and oceanographic significance of an iconic succession of the Basin and Range. In Henderson, C.M., Ritter, S. and Snyder, W.S. (eds.), Late Paleozoic and Early Mesozoic Tectonostratigraphy and Biostratigraphy of western Pangea,

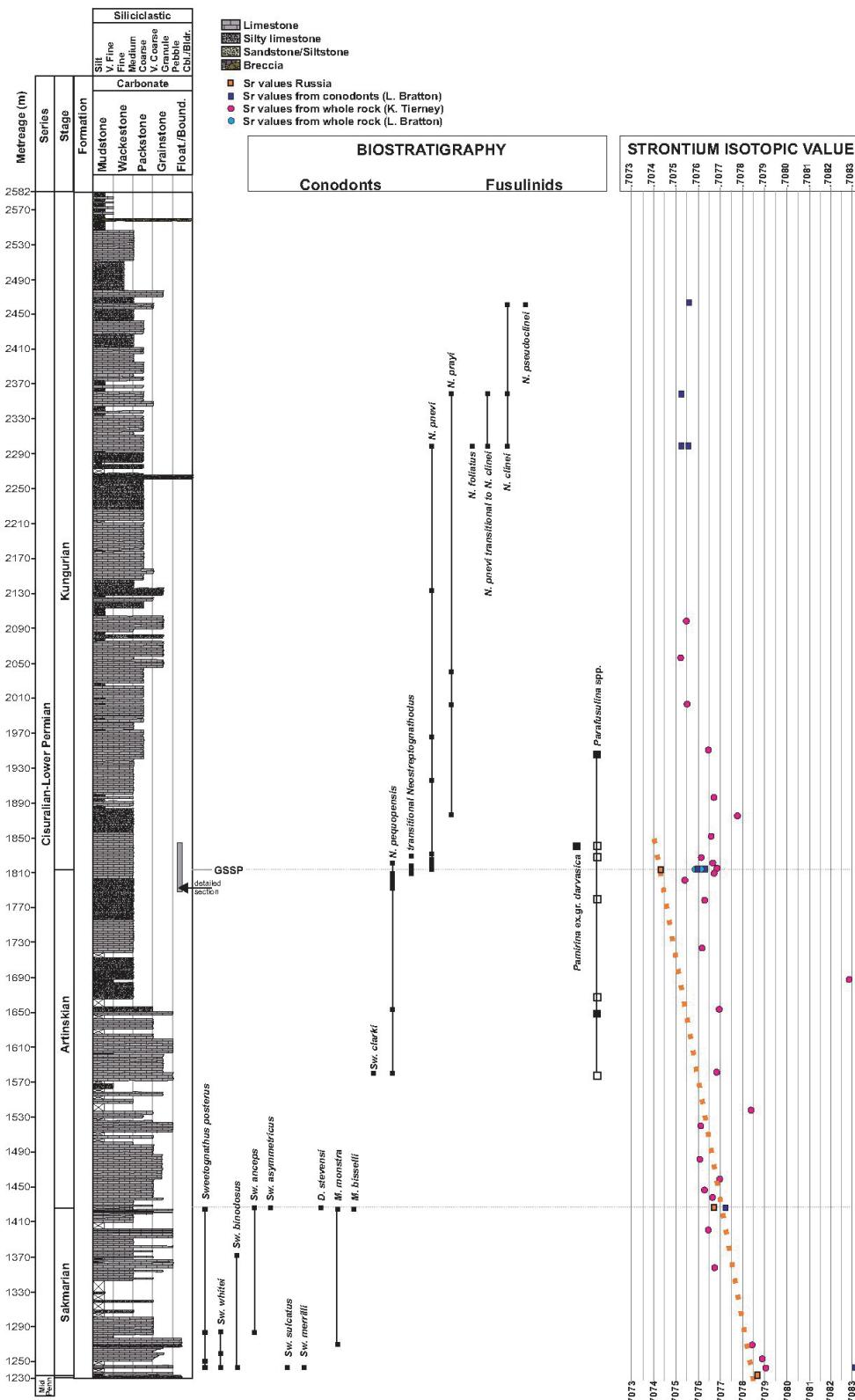


Fig. 1. Rockland Section (from Bratton, 2024) showing conodont biostratigraphy and strontium isotopes. The base-Kungurian GSSP is at 1813.5 metres. Pink circles are whole rock data from Tierney (2010); data above 1517 m were produced in 2023 by Kate Tierney with costs supported by SPS funds. Blue squares are conodont data produced by Luke Bratton as part of his 2024 MSc thesis. Orange squares are Sr isotopic ratios values at GSSP sections at Usolka (Sakmarian) and Dal'ny Tulkas (Artinskian) as well as the base-Kungurian level at Mechetlino; these are connected by a dashed orange line.



Fig. 2. Here Mike Read, Charles Henderson and Lucia Angiolini navigate thick grainstone units of Pennsylvanian age following a good day in the Permian above.



Fig. 5. Charles Henderson viewing an upper Asselian outcrop in Carlin Canyon area that we refer to as the "Bryozoan Garden". It is in part interpreted as a bafflestone and includes very abundant silicified bryozoans, as well as brachiopods, echinoderms and conodonts.



Fig. 3. Charles Henderson, Lucia Angiolini and Mike Read standing just above the base-Kungurian immediately below bed 12 (=bed 11.6) at 1813.5 metres.



Fig. 4. Charles Henderson and Mike Read comparing notes immediately above the upper Asselian sequence boundary at Carlin Canyon.

Special Publication 113: SEPM (Society for Sedimentary Geology), Broken Arrow, Oklahoma, p. 34–71. <https://doi.org/10.2110/sepmfsp.113.12>

Bratton, L., 2024. Strontium Isotope Stratigraphy: Case Studies of Upper Carboniferous and Lower Permian Successions from southeast Utah and northeast Nevada. Unpublished MSc thesis, University of Calgary, 101 pp.

Henderson, C.M., Wardlaw, B.R., Davydov, V.I., Schmitz, M.D., Schiappa, T.A., Tierney, K.E. and Shen, S.Z., 2012. Proposal for the base-Kungurian GSSP. *Permophiles*, n. 56, p. 8–21.

McArthur, J.M., Howarth, R.J., Shields, G.A. and Zhou, Y., 2020. Strontium Isotope Stratigraphy. In *Geologic Time Scale 2020*, Elsevier, p. 211–238. <https://doi.org/10.1016/B978-0-12-824360-2.00007-3>

Tierney, M.S., 2010. Carbon and strontium isotope stratigraphy of the Permian from Nevada and China: Implications from an icehouse to greenhouse transition (Publication No. 3424605) [Doctoral dissertation, Ohio State University] ProQuest Dissertations.

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Age and correlation of the Lower Permian Hueco Group in the Robledo Mountains, New Mexico, USA: A critique of Calvo González et al.

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Introduction

In southern New Mexico and West Texas, USA, strata of the Hueco Group record Early Permian marine and nearshore paleoenvironments in the equatorial tropics of western Pangea. Age assignments and the correlation of these strata have long been based on fusulinid biostratigraphy, with some other biostratigraphic data based on ammonoids, brachiopods, conodonts and ostracodes. Calvo González (2022) and Calvo González et al. (2023a, b) have recently challenged these correlations with new conodont data from the Hueco Group strata in the Robledo Mountains of southern New Mexico. Here, we question the age assignments and correlations of Calvo-González et al.

Stratigraphic setting

The Robledo Mountains section of the Hueco Group is one of five Hueco outcrop areas in southern New Mexico and West Texas for which biostratigraphic data are available (Fig. 1): (1) Robledo Mountains, just northwest of Las Cruces, New Mexico; (2) Doña Ana Mountains, just across the Rio Grande from the Robledo Mountains, 14 km to the northeast; (3) southern San Andres Mountains, 42 km to the northeast; (4) Franklin Mountains near El Paso in Texas, 70 km to the southeast; and (5) the type section of the Hueco Group in the Hueco Mountains of West Texas, 99 km to the southeast. In the Doña Ana and San Andres Mountains the same formation-rank units (except the Apache Dam Formation) as in the Robledo Mountains are present (Lucas et al., 2002; Krainer et al., 2003, 2005, 2009). But, because of facies changes, the formation-rank units in the Franklin and Hueco Mountains have different names.

There is a long- and well-established homotaxis/correlation of the formation-rank units of the Hueco Group in all five locations (e.g., Kottlowski, 1963; Harbour, 1972; Jordan, 1975; Kottlowski et al., 1975; Lucas et al., 1998, 2011a, b, 2015; Wahlman and King, 2002; Lucas, 2014; Wahlman, 2019) (Fig. 2). This makes it possible to compare biostratigraphic data from all five mountain ranges, and these data reinforce long established correlations

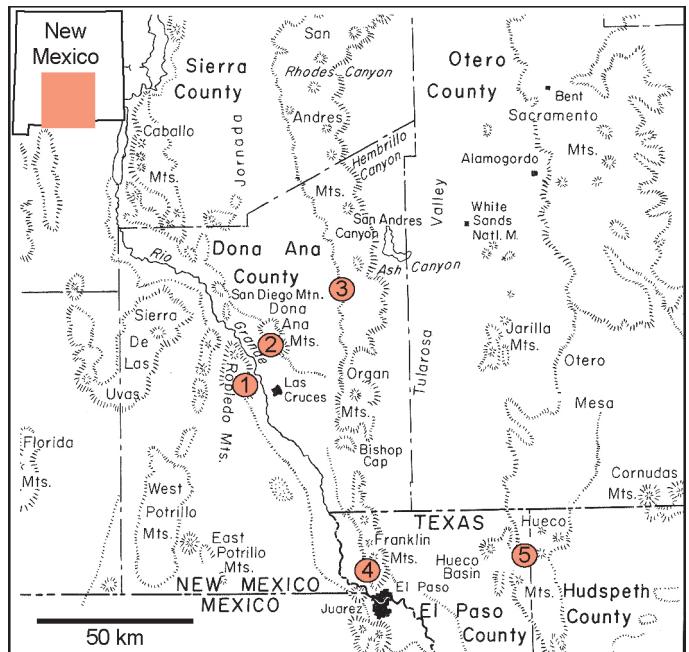


Fig. 1. Map of part of southern New Mexico and West Texas, USA, showing the location of five outcrop areas of the Lower Permian Hueco Group for which biostratigraphic data exist: 1 = Robledo Mountains, 2 = Doña Ana Mountains, 3 = Southern San Andres Mountains, 4 = Franklin Mountains and 5 = Hueco Mountains.

among the Hueco Group formations (which were ignored by Calvo González et al., and also by Henderson and Read (2023)). Particularly significant to this homotaxis/correlation is the presence in all five mountain ranges of a red-bed siliciclastic unit stratigraphically high in the Hueco Group—Robledo Mountains Formation in the Robledo, Doña Ana and San Andres mountains, Trans Mountain Road Member of Alacran Mountain Formation in the Franklin Mountains and Deer Mountain Red Shale Member of the Alacran Mountain Formation in the Hueco Mountains (Fig. 2). These units have long been considered to represent red-bed tongues of the Abo Formation to the north and likely reflect a single tectonic event in the Abo-Hueco depositional system (e.g., Jordan, 1975; Mack et al., 1988; Lucas et al., 2011a).

In the Robledo Mountains, the Hueco Group consists of four formations (ascending): (1) Shalem Colony Formation, 127–156 m thick, mostly thick bedded and coarse-grained wackestones and grainstones; (2) Community Pit Formation, 93–177 m thick, mostly shale, muddy limestone and dolomitic limestone; (3) Robledo Mountains Formation, 90–125 m thick, mostly shale, grainy limestone and red-bed siliciclastics (sandstone, siltstone and mudstone); and (4) Apache Dam Formation, at least 107 m thick and mostly algal limestone and shale (Lucas et al., 1995, 1998, 2015; Krainer et al., 2015) (Figs. 2–3).

Ages and correlations

We review age data and correlations of the Hueco Group strata in the Robledo Mountains (Fig. 3) and contrast them with the age assignments of Calvo González et al. Most of the published age assignments, based on fusulinids, have been to the North American Wolfcampian and Leonardian stages. Here, we follow Lucas et al. (2022) in correlating the base of the Leonardian to the late Artinskian. To be consistent with Calvo

Age		1 Robledo Mountains (Lucas et al., 2015)	2 Doña Ana Mountains (Krainer et al., 2005, 2009)	3 San Andres Mountains (Lucas et al., 2002)	4 Franklin Mountains (Lucas et al., 2011a)	5 Hueco Mountains (Williams, 1963)
Artinskian	Wolfcampian	Apache Dam Formation	faulted	Yeso Group	Alacran Mountain Formation	Alacran Mountain Formation
		Robledo Mountains Formation		Abo Formation	TMR	DMS
		Community Pit Formation	Hueco Group	Robledo Mountains Formation	Cerro Alto Formation	Cerro Alto Formation
		Shalem Colony Formation	Hueco Group	Community Pit Formation		
Sakmarian	middle (Nealian)	Shalem Colony Formation	Hueco Group	Shalem Colony Formation	Hueco Canyon Formation	Hueco Canyon Formation
					Powwow Mbr.	
Asselian	late (Lenoxian)					

DMS = Deer Mountain Red Shale Member, L = Leonardian, TMR = Trans Mountain Road Member

Fig. 2. Correlation of the five Hueco Group outcrop areas shown in Fig. 1. These are long accepted correlations based primarily on stratigraphic homotaxis of the lithostratigraphic units and fusulinid biostratigraphy. Numbers at tops of columns correspond to numbered locations in Fig. 1. Red-colored units are those that contain significant amounts of siliciclastic red beds.

González et al., who use the conodont-based definition of the Permian base; the Permian (Asselian) base here is the base of the middle Wolfcampian (Nealian) and the lower Wolfcampian (“Bursumian”) is Virgilian (Gzhelian).

Horquilla Formation

In the Robledo Mountains, the Hueco Group sits on the Horquilla Formation (Krainer et al., 2015; Lucas et al., 2015). There are no strata that can, on a lithostratigraphic basis, be called Bursum Formation, but there is an interval of the upper Horquilla-lower Hueco that contains Bursum-age (“Bursumian”) fusulinids (Thompson, 1954; Wahlman and King, 2002; Krainer et al., 2015).

Wahlman and King (2002) documented fusulinids from the upper part of the Horquilla Formation and lower part of the Shalem Colony Formation in the northern Robledo Mountains. [Note that their base of the Shalem Colony Formation (bed 232 of Krainer et al., 2015) is stratigraphically higher than the base used by Krainer et al. (2015)]. Wahlman and King identified Bursum-age fusulinids from two stratigraphic intervals that correspond to beds 181-189 and 209-215 of Krainer et al. (2015), and Krainer et al. (2015) identified similar-age fusulinids as low as unit 140 of that stratigraphic section. This means that in the Robledo Mountains Bursum-age fusulinids are present from the upper part of the Horquilla Formation through the lower part of the Shalem Colony Formation. These Virgilian (Gzhelian) fusulinids thus bracket the conodonts from bed 191 that Krainer et al. (2015) identified as *Streptognathodus binodosus* and *S. conjunctus* and assigned a late Virgilian age. Calvo-González et al. revised the identifications to *S. longus*, *S. grandis* and *S. paraisolatus*. They assigned these conodonts to the *S. glenisteri* zone, which is the oldest Asselian conodont zone of Henderson (2018). However, the bracketing fusulinids indicate that this age assignment is too

young.

The re-identifications of the *Streptognathodus* species by Calvo González et al. used the taxonomic names of early Asselian species of Chernykh (2005, 2006), taxa apparently known only from the deep-water deposits in the Southern Urals (Henderson, 2018, p. 122). The Robledo specimens instead fit better with well-known North American late Gzhelian species of Boardman et al. (2009) that have been reported from several areas of shallow water carbonates in the United States Midcontinent and Southwest. It is likely that, like later *Sweetognathus* species (e.g., Mei and Henderson, 2001), a combination of paleogeographic and paleoecological factors may have restricted *Streptognathodus* species to different provinces. Distinct species groups assigned to “*Streptognathodus*” in the Late Pennsylvanian occur in different geographic regions (Barrick et al., 2023), and this may be true of Early Permian species. Also, the species concepts of *Streptognathodus* in both Chernykh (2005, 2006) and Boardman et al. (2009) are vague to confusing, and revisions will be needed to determine the best interpretations of species evolution in this group. The upper Horquilla Formation conodonts described by Krainer et al. (2015) are not as young as Asselian.

Shalem Colony Formation

Fusulinids from the Shalem Colony Formation in the Robledo Mountains have been documented by Thompson (1954), Wahlman and King (2002), Krainer et al. (2015) and Lucas et al. (2015). In the lower Shalem Colony Formation, Wahlman and King (2002) identified Bursum age fusulinids from units 209-213 of Krainer et al. (2015, fig. 6) and species of *Leptotriticites*, *Pseudoschwagerina* and *Schwagerina* that indicate a middle Wolfcampian age from units 252-256 of Krainer et al. (2015, fig. 6).

Some of the same fusulinid genera and species are found

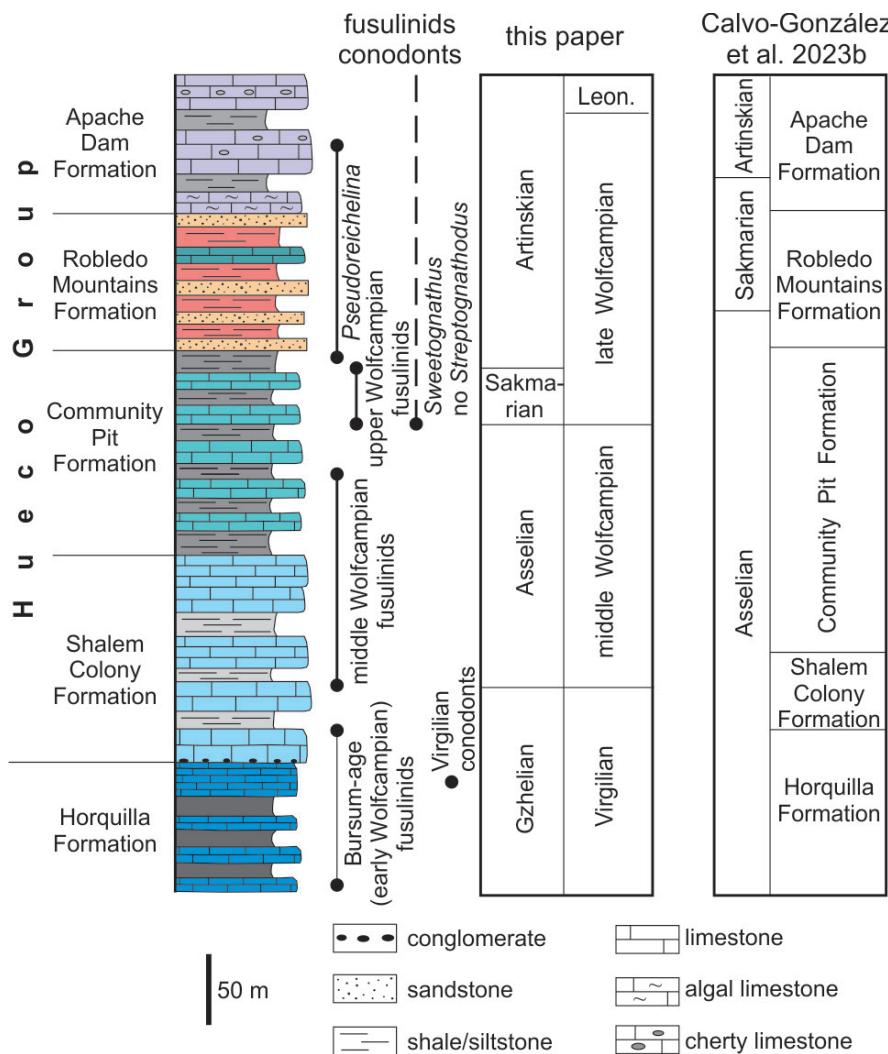


Fig. 3. Summary of Hueco Group lithostratigraphy (lithology schematic) and some important biostratigraphic data in the Robledo Mountains, with the correlations advocated here contrasted with those of Calvo González et al. (2023b).

in the Shalem Colony Formation in the Doña Ana Mountains (Krainer et al., 2009) and the southern San Andres Mountains (Kottlowski et al., 1956; Bachman and Myers, 1969). In the Doña Ana Mountains, Krainer et al. (2009) identified two foraminiferal assemblages in the Shalem Colony Formation: (1) a lower assemblage with *Triticites pinguis* of Bursum age and (2) an upper assemblage with *Geinitzina* of middle Wolfcampian age. In the Franklin Mountains and the Hueco Mountains the same fusulinid fauna is present in the Hueco Canyon Formation (Dunbar and Skinner, 1937; Williams, 1966; Harbour, 1972; Lucas et al., 2011b). Thus, in the Franklin Mountains, the Hueco Canyon Formation has a fusulinid assemblage dominated by typical middle Wolfcampian species such as *Pseudoschwagerina uddeni*, *P. beedei*, *P. texana* and *Monodexodina bispatularis*.

The fusulinid assemblages support correlation of the Shalem Colony and Hueco Canyon formations strata in all five mountain ranges, although the lower part of the Shalem Colony Formation in the Robledo and Doña Ana Mountains is as old as late Virgilian, older than the Hueco base in the Franklin and Hueco mountains.

Lucas et al. (2015) indicated that the Shalem Colony

Formation extends in age from the late Gzhelian through the middle Sakmarian (though their figures 41-42 erroneously showed it as only of Asselian age). Calvo-González et al. restricted the age range of the Shalem Colony Formation to a short interval near the base of the Asselian. This seems to have been based on their conclusion that the Virgilian conodonts documented by Krainer et al. (2015) are Asselian, but these conodonts are from the upper Horquilla Formation, not from the Shalem Colony Formation. Shalem Colony fusulinids indicate it encompasses the late Virgilian (Gzhelian) and much of the middle Wolfcampian (Nealian/Asselian) (Fig. 3).

Community Pit Formation

In the Robledo Mountains, Lucas et al. (2015) reported fusulinids from the middle of the Community Pit Formation (*Pseudoschwagerina*, *Nankinella?* and *Ellesmerella*) and the upper part of the formation (*Paraschwagerina* and *Oketaella*) that indicate a middle Wolfcampian age close to the middle-late Wolfcampian (Asselian-Sakmarian) boundary. This suggests that the base of the Sakmarian is near the middle of the Community Pit Formation.

In the Doña Ana Mountains, Krainer et al. (2009) documented the local lowest occurrence of *Pseudovermiporella* and took that to indicate a Sakmarian age for the Community Pit Formation. They documented *Pseudoreichelina* in the top of the Community Pit Formation and in the Robledo Mountains Formation and considered those records to be of Artinskian age.

In the Franklin Mountains, Harbour (1972) reported *Pseudoschwagerina uddeni*, *P. gerontica*?, *P. ?texana* and *P. texana* var. *ultima* from the base of his “middle unit” (= Cerro Alto Formation), indicating a middle Wolfcampian age. In the Hueco Mountains, Williams (1963) documented the fusulinids *Schwagerina eolata* and *S. neolata* from the Cerro Alto Formation and assigned them a late Wolfcampian age. The ammonites documented by Miller and Parizek (1948) from near Otero Mesa in southern New Mexico are from the Cerro Alto Formation (one of us [SGL] relocated their localities) and were also assigned a late Wolfcampian age.

Henderson (2018) stated that *Sweetognathus* replaced *Streptognathodus* across the Asselian-Sakmarian boundary. There are no *Streptognathodus* in the Community Pit Formation (nor are there any in the homotaxial/correlative Cerro Alto Formation in the Franklin Mountains: Ritter, 1986), but there are *Sweetognathus* present in both the Community Pit and Cerro Alto formations, and that further suggests the upper Community Pit Formation likely postdates the Asselian-Sakmarian boundary.

Calvo González et al. assigned the Community Pit Formation a mid-late Asselian age based on conodonts they identified, however the age assignments and correlations discussed here indicate a longer temporal range for the formation. Fusulinid data and regional correlations indicate that the Community Pit Formation extends from the middle to late Wolfcampian, Asselian through early Artinskian (Fig. 3).

Robledo Mountains Formation

In the Doña Ana Mountains, Krainer et al. (2003) documented *Pseudoreichelina* from the upper Robledo Mountains Formation and lower Apache Dam Formation (cf. Krainer and Lucas, 1995, fig. 3, section C). Lucas et al. (2015) also documented *Pseudoreichelina* in the lower part of the Apache Dam Formation in the Robledo Mountains. The aberrant fusulinid *Pseudoreichelina* is never common but has a broad geographic distribution in strata of Artinskian age (Douglass and Nestell, 1974; Wahlman et al., 2017) and also has Kungurian records (Davydov et al., 2013). Its presence in the stratigraphic interval uppermost Community Pit-Robledo Mountains-middle Apache Dam formations indicates that these are strata of Artinskian age.

Lucas et al. (1995, 1998) reported identifications of conodonts from the lower Robledo Mountains Formation by the late Bruce Wardlaw: *Diplognathodus* sp., *Hindeodus excavatus*, *Neostreptognathodus clarki*, *Sweetina festiva* and *Sweetognathus expansus*—that Wardlaw considered to be of late Artinskian age. However, these conodonts were never illustrated, so their taxonomy cannot be evaluated. Kozur and LeMone (1995) reported conodonts from the lower Robledo Mountains Formation that they assigned to the *Mesogondolella bisselli*-*Sweetognathus merrilli* Zone that they considered to be of late Sakmarian age, but Calvo González et al. (2023b) discounted their identifications

of *Sw. merrilli* and *Sw. posterus*. Ostracods and ammonoids from the upper part of the Robledo Mountains Formation were judged to be close in age to the Wolfcampian-Leonardian boundary (Kietzke and Lucas, 1995; Kues, 1995).

The Robledo Mountains Formation contains extensive-trace fossil assemblages in its red-bed intervals that include tetrapod footprints – common *Batrachichnus*, *Dimetropus* and *Dromopus* and less common *Amphisauropus*, *Hyloidichnus*, *Notalacerta* and *Robledopus* (Voigt and Lucas, 2015). These are characteristic of the *Dromopus* biochron of Lucas (2007), which predates the *Erpetopus* biochron (dominated by captorhinomorph footprints) recognized from footprints in the uppermost Abo Formation and lower Yeso Group to the north (Voigt and Lucas, 2017). From footprint records in Arizona, New Mexico, Texas and Europe we know the boundary of the *Dromopus* and *Erpetopus* biochrons is of middle Artinskian age (Voigt and Lucas, 2018; Marchetti et al., 2022). This indicates an age of the Robledo Mountains Formation footprint ichnoassemblages no younger than middle Artinskian.

In the Franklin Mountains, middle Wolfcampian fusulinids are present in the Alacran Mountain Formation stratigraphically below the Trans Mountain Road Member, and Alacran Mountain strata above contain an upper Wolfcampian fusulinid assemblage (Williams, 1966; Harbour, 1972; Lucas et al., 2011a). Fusulinids thus indicate the Trans Mountain Road Member is close in age to the middle/late Wolfcampian boundary age. In the Hueco Mountains, the base of the Leonardian is ~ 85 m above the top of the Deer Mountain Red Shale Member, which is of late Wolfcampian age (Thompson, 1954; Williams, 1963).

Ritter (1986) documented conodonts from the Cerro Alto and Alacran Mountain formations in the Franklin Mountains. Significant records include: (1) *Homeirognathus huecoensis* throughout the upper Cerro Alto Formation and the entire Alacran Mountain Formation; (2) *Diplognathodus stevensi* through the entire Cerro Alto section and in the lower half of the Alacran Mountain Formation; and (3) one record of “*Neogondolella*” *idahoensis* in the upper Alacran Mountain Formation. As Ritter (1986) noted, the record of “*N.*” *idahoensis* indicates a Leonardian age (see Wardlaw and Nestell, 2019). *D. stevensi* has a long stratigraphic range as does *H. huecoensis*; both taxa cross the Wolfcampian-Leonardian boundary.

In the Robledo and Doña Ana mountains, the presence of *Pseudoreichelina* in the Robledo Mountains Formation indicates an Artinskian age, and the footprints indicate an age no younger than middle Artinskian. The homotaxial/correlative siliciclastic red bed units of the Hueco Group in the Franklin Mountains (Trans Mountain Road Formation) and Hueco Mountains (Deer Mountain Red Shale Member) are both close in age to the middle-late Wolfcampian boundary, and that supports an early-middle Artinskian age assignment.

From the Robledo Mountains Formation, Calvo-González et al. reported the conodonts *Sweetognathus posterus* and *Sw. sulcatus* and considered them to indicate an age range of late Asselian-Sakmarian. They also claimed that the questionable record of *Amphoratheca*? reported by Lucas et al. (2015) indicates an Asselian age. However, the fusulinid data indicate an Artinskian age for the Robledo Mountains Formation younger than the Asselian-Artinskian age of the underlying Community

Pit Formation (Fig. 3).

Apache Dam Formation

No fusulinids other than *Pseudoreichelina* are known from the Apache Dam Formation in the Robledo Mountains. But, in the Franklin Mountains, the Alacran Mountain Formation contains fusulinid species that characterize the late Wolfcampian—*Pseudoschwagerina gerontica*, *P. convexa*, *Schwagerina nelsoni* and *S. franklinensis* (Williams, 1966). Williams (1966) reported “*Schwagerina* sp. cf. *S. crassitectoria*” from the middle part of the Alacran Mountain Formation in the Franklin Mountains, but did not describe, illustrate or discuss the specimens(s) upon which the identification was based. However, note that two conodont taxa from the upper Alacran Mountain Formation in the Franklin Mountains, *Sweetognathus asymmetricus* and *Mesogondolella idahoensis*, are, as Ritter (1986) noted, known in the type Leonardian and thus indicate a Leonardian age.

The Alacran Mountain Formation above the Deer Mountain Red Shale Member in the Hueco Mountains has two fusulinid assemblages of different ages: (1) a stratigraphically lower assemblage of *Pseudoschwagerina gerontica*, *P. convexa*, *P. texana*, *P. uddeni*, and *Schwagerina diversiformis* of late Wolfcampian age; and (2) a stratigraphically higher assemblage of *Schwagerina crassitectoria* and *S. franklinensis* of early Leonardian age (Thompson, 1954; Williams, 1963), though Wahlman (2019) considered the entire Alacran Mountain Formation to be of late Wolfcampian age.

Calvo-González et al. (2023b, p. 31) reported supposed “age-diagnostic conodont taxa” from the Apache Dam Formation in the Robledo Mountains—*Sweetognathus* cf. *anceps*, *Sweetognathus* sp. and *Diplognathodus stevensi*, and assigned them a Sakmarian age. However, *D. stevensi* has Kungurian records (Wardlaw and Nestell, 2019). The specimen from the Apache Dam Formation that Calvo González et al. (2023b, fig. 20.15) identify as *Sweetognathus* cf. *anceps* is a poorly preserved P1 element with a slightly curved carina and partial free blade with at least 10 narrow and isolated nodes. It bears little resemblance to *S. anceps*, which has broader nodes that are usually pustulose and are fused transversely or sometimes connected by a transverse ridge (e.g., Chernykh, 2006, pl. 21, figs. 13-15; Petryshen et al., 2020, fig. 2K; Afanasieva et al., 2022, fig. 5d). As poorly preserved as it is, this specimen may be reworked.

Thus, the conodonts from the Apache Dam Formation documented by Calvo González et al. are not age diagnostic. We correlate the Apache Dam Formation to the upper part of the Alacran Mountain Formation (Fig. 2), so the the Apache Dam Formation is of late Wolfcampian-early Leonardian (middle?-late Artinskian) age.

End of the Late Paleozoic Ice Ages (LPIA)

Montañez (2023) noted that the apex of the Late Paleozoic glaciation started in the Gzhelian and continued into the Sakmarian. A return to glacial conditions occurred in west-central Gondwana in the Sakmarian. The third and terminal deglaciation for this region occurred near the Artinskian-Kungurian boundary. Restricted ice sheets existed in parts of central and eastern Gondwana until about the Lopingian. Montañez (2023)

pointed out that a widespread loss of cyclicity in post-mid Sakmarian sedimentary successions is observed in lower-latitude successions. Thus, ice sheets decreased during the Artinskian but existed locally until the Lopingian.

According to Calvo González et al., in the Robledo Mountains differences in the amplitude of sea-level fluctuations between cycloths in the Horquilla/Shalem Colony and the Community Pit/Robledo Mountains formations may be linked to the volume of water that was contained in ice sheets during the main phase of the LPIA. They argued that Pennsylvanian and lower Asselian cycloths of the Horquilla and Shalem Colony formations were likely caused by glacio-eustatic sea-level fluctuations during the peak of the LPIA. Middle to upper Asselian cycloths of the Community Pit and Robledo Mountains formations were interpreted to represent sea-level fluctuations of more moderate amplitude in sea-level fluctuations during the demise of the LPIA before its collapse at the Asselian-Sakmarian boundary.

However, once correct age assignments are made to the Hueco Group strata in the Robledo Mountains, they provide no evidence that the Gondwana ice sheets collapsed at the Asselian-Sakmarian boundary and that glacio-eustatic sea-level fluctuations did not occur during the Sakmarian as argued by Calvo González et al. (2023a, b). We thus agree with the critical comments of Forke (2024) regarding correlations of the Lower Permian strata in the Austrian Carnic Alps and reject the correlations of the Robledo Mountains Hueco Group strata proposed by Calvo González (2022) and Calvo González et al. (2023a, b) and their inferred timing of the end of the LPIA.

References

- Afanasyeva, M.S., Chernykh, V.V., Sungatullina, G.M., Sungatullin, R.Kh. and Zbukova, D.V., 2022. Radiolarians, conodonts, and palynomorphs from the Sakmarian–Artinskian boundary beds (lower Permian) in the Dal’ny Tulkas section, South Urals, Russia. Paleontological Journal, v. 56, p. 975–1025.
- Bachman, G.O. and Myers, D.A., 1969. Geology of the Bear Peak area Doña Ana County, New Mexico. U. S. Geological Survey Bulletin 1271-C, 46 pp.
- Barrick, J.E., Hogencamp, N.J. and Rosscoe, S.J., 2023. Evolutionary patterns in Late Pennsylvanian conodonts. Geological Society, London, Special Publications, v. 535, p. 383–408.
- Boardman, D.R.II, Wardlaw, B.R. and Nestell M.K., 2009. Stratigraphy and conodont biostratigraphy of the uppermost Carboniferous and lower Permian from the North American mid-continent. Kansas Geological Survey, Bulletin, v. 255, 253pp.
- Calvo González, D., 2022. Correlation between the Cisuralian successions of the Robledo Mountains (New Mexico) and the Carnic Alps (Austria) integrating conodont and foraminifer biostratigraphy. Permophiles, n. 72, p. 61–67.
- Calvo Gonzalez, D., Beauchamp, B. and Henderson, C.M., 2023a. Microfacies analysis and biostratigraphy of lower Permian carbonate-dominated cyclothem, Robledo Mountains (New Mexico, USA) and Carnic Alps (Austria): insights into the stepwise decline of Late Paleozoic ice age (LPIA).

- Permophiles, n. 75, p. 32–39.
- Calvo González, D., Beauchamp, B. and Henderson, C.M., 2023b. High-frequency sequence stratigraphy of Pennsylvanian-lower Permian carbonate successions of the Robledo Mountains, New Mexico and the Carnic Alps, Austria: a record of the acme and demise of the late Paleozoic ice age. *Facies*, v. 69, p. 2.
- Chernykh, V.V., 2005. Zonal methods and biostratigraphy – zonal scheme for the Lower Permian of the Urals according to conodonts. Institute of Geology and Geochemistry, Urals Branch of the Russian Academy of Science, Ekaterinburg (in Russian).
- Chernykh, V.V., 2006. Lower Permian conodonts in the Urals. Institute of Geology and Geochemistry, Uralian Branch of the Russian Academy of Sciences: Ekaterinburg (in Russian).
- Davydov, V.I., Krainer, K. and Chernykh, V., 2013. Fusulinid biostratigraphy of the lower Permian Zweikofel Formation (Rattendorf Group; Carnic Alps, Austria) and lower Permian Tethyan chronostratigraphy. *Geological Journal*, v. 48, p. 57–100.
- Douglass, R.C. and Nestell, M.K., 1974. The Permian fusulinid genus *Pseudoreichelina* from the Pequop Formation, Spruce Mountains, Elko County, Nevada. *Journal of Paleontology*, v. 48, p. 1170–1173.
- Dunbar, C.O. and Skinner, J.W., 1937. Permian Fusulinidae of Texas. *The University of Texas Bulletin*, no. 3701, v. 3, n. 2, p. 518–825.
- Forke, H.C., 2024. Carnic Alps stratigraphy – quo vadis? (A comment to Calvo González et al. 2023). *Permophiles*, n. 76, p. 13–25.
- Harbour, R.L., 1972. Geology of the northern Franklin Mountains, Texas and New Mexico. U.S. Geological Survey, *Bulletin*, n. 1298, 129 pp.
- Henderson, C.M., 2018. Permian conodont biostratigraphy. Geological Society, London, Special Publications, v. 450, p. 119–142.
- Henderson, C.M. and Read, M.T., 2023. Correlation chart for the lower Permian of the western USA. *Permophiles*, n. 74, p. 41–44.
- Jordan, C.F., 1975. Lower Permian (Wolfcampian) sedimentation in the Orogenome basin, New Mexico. New Mexico Geological Society, Guidebook p. 109–117.
- Kietzke, K.K. and Lucas, S.G., 1995. Some microfossils from the Robledo Mountains Member of the Hueco Formation, Doña Ana County, New Mexico. *New Mexico Museum of Natural History and Science, Bulletin*, v. 6, p. 57–62.
- Kottlowski, F., 1963. Paleozoic and Mesozoic strata of southwestern and south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, *Bulletin*, v. 79, 100 pp.
- Kottlowski, F.E., LeMone, D.V. and Seager, W.R., 1975. Marginal marine and continental facies of the Lower Permian in central New Mexico. *Permian Basin Section SEPM, Publication*, v. 75–65, p. 119–124.
- Kottlowski, F.E., Flower, R.H., Thompson, M.L. and Foster, R. W., 1956. Stratigraphic studies of the San Andres Mountains, New Mexico. *New Mexico Bureau of Mines and Mineral Resources, Memoir* 1, 132 pp.
- Kozur, H. and LeMone, D.V., 1995. The Shalem Colony section of the Abo and upper Hueco members of the Hueco Formation of the Robledo Mountains, Doña Ana County, New Mexico. Stratigraphy and new conodont-based age determinations. *New Mexico Museum of Natural History and Science, Bulletin*, v. 6, p. 39–55.
- Krainer, K., Lucas, S.G. and Spielmann, J.A., 2005. Hueco Group (Lower Permian) stratigraphy in the Doña Ana Mountains, southern New Mexico. *New Mexico Museum of Natural History and Science, Bulletin*, v. 31, p. 60–73.
- Krainer, K., Vachard, D. and Lucas, S.G., 2003. Microfacies and microfossil assemblages (smaller foraminifers, algae, pseudoalgae) of the Hueco Group and Laborcita Formation (Upper Pennsylvanian-lower Permian), south-central New Mexico, USA. *Rivista Italiana di Paleontologia e Stratigrafia*, v. 109, p. 3–36.
- Krainer, K., Vachard, D. and Lucas, S.G., 2009. Facies, microfossils (smaller foraminifers, calcareous algae) and biostratigraphy of the Hueco Group, Doña Ana Mountains, southern New Mexico, USA. *Rivista Italiana di Paleontologia e Stratigrafia*, v. 115, p. 3–26.
- Krainer, K., Lucas, S.G., Vachard, D. and Barrick, J.E., 2015. The Pennsylvanian-Permian section at Robledo Mountain, Doña Ana County, New Mexico, USA. *New Mexico Museum of Natural History and Science, Bulletin*, v. 65, p. 9–41.
- Kues, B.S., 1995. Marine fauna of the early Permian (Wolfcampian) Robledo Mountains Member, Hueco Formation, southern Robledo Mountains, New Mexico. *New Mexico Museum of Natural History and Science, Bulletin*, v. 6, p. 63–90.
- Lucas, S.G., 2007. Tetrapod footprint biostratigraphy and biochronology. *Ichnos*, v. 14, p. 5–38.
- Lucas, S.G., 2014. Trace fossils from the Lower Permian Yeso Group, Otero Mesa, Otero County, New Mexico. *New Mexico Geological Society, Guidebook*, v. 65, p. 303–310.
- Lucas, S.G., Anderson, O.J., Heckert, A.B. and Hunt, A.P., 1995. Geology of early Permian tracksites, south-central New Mexico. *New Mexico Museum of Natural History and Science, Bulletin*, v. 6, p. 13–32.
- Lucas, S.G., Heckert, A.B., Estep, J.W. and Cook, C.W., 1998. Stratigraphy of the Lower Permian Hueco Group in the Robledo Mountains, Doña Ana County, New Mexico. *New Mexico Museum of Natural History and Science, Bulletin*, v. 12, p. 43–54.
- Lucas, S.G., Krainer, K. and Kues, B.S., 2002. Stratigraphy and correlation of the Lower Permian Hueco Group in the southern San Andres Mountains, Doña Ana County, New Mexico. *New Mexico Geological Society, Guidebook* 53, p. 223–240.
- Lucas, S.G., Krainer, K., Corbitt, L., DiBenedetto, J. and Vachard, D., 2011a. The Trans Mountain Road Member, a new stratigraphic unit of the Lower Permian Hueco Group, northern Franklin Mountains, Texas. *New Mexico Museum of Natural History and Science, Bulletin*, v. 53, p. 93–109.
- Lucas, S.G., Krainer, K., and Vachard, D., 2011b. Stratigraphy, depositional environments, age, and regional tectonic

- significance of the Powwow Member of the Hueco Canyon Formation, Lower Permian of the Hueco Mountains, West Texas. West Texas Geological Society Bulletin, v. 50, p. 20–40.
- Lucas, S.G., Krainer, K. and Vachard, D., 2015. The Lower Permian Hueco Group, Robledo Mountains, New Mexico (U.S.A.). New Mexico Museum of Natural History and Science, Bulletin, v. 65, p. 43–95.
- Lucas, S.G., Henderson, C., Barrick, J.E. and Krainer, K., 2022. Conodonts and the correlation of the Lower Permian Yeso Group, New Mexico, USA. Stratigraphy, v. 19, p. 77–94.
- Mack, G.H., James, W.C., and Seager, W.C., 1988. Wolfcampian (early Permian) stratigraphy and depositional environments in the Doña Ana and Robledo mountains, south-central New Mexico. Permian Basin Section of SEPM, Publication, 88–28, p. 97–106.
- Marchetti, L., Forte, G., Kustatscher, E., DiMichele, W.A., Lucas, S.G., Roghi, G., Juncal, M.A., Hartkopf-Fröder, C., Krainer, K., Morelli, C. and Ronchi, A., 2022. The Artinskian Warming Event: an Euramerican change in climate and the terrestrial biota during the early Permian. Earth-Science-Reviews, v. 226, p. 103922.
- Mei, S.L. and Henderson, C.M., 2001. Evolution of Permian conodont provincialism and its significance in global correlation and paleoclimate implication. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 170, p. 237–260.
- Miller, A.K. and Parizek, E.J., 1948. A lower Permian ammonoid fauna from New Mexico. Journal of Paleontology, v. 22, p.350–358.
- Montañez, I.P., 2023. Current synthesis of the penultimate icehouse and its imprint on the Upper Devonian through Permian stratigraphic record. Geological Society, London, Special Publications, v. 512, p. 213–245.
- Petryshen, W., Henderson, C.M., De Baets, K. and Jarochowska, E., 2020. Evidence of parallel evolution in the dental elements of *Sweetognathus* conodonts. Proceedings of the Royal Society B, v. 287, p. 20201922.
- Ritter, S.M., 1986. Taxonomic revision and phylogeny of post-Early Permian crisis *bisselli-whitei* zone conodonts with comments on late Paleozoic diversity. Geologica et Palaeontologica, v. 20, p. 139–165.
- Thompson, M.L., 1954. American Wolfcampian fusulinids. University of Kansas, Paleontological Contributions, Protozoa, Article 5, 226 pp.
- Voigt, S. and Lucas, S.G., 2015. Permian tetrapod ichnodiversity of the Prehistoric Trackways National Monument (south-central New Mexico, U.S.A.). New Mexico Museum of Natural History and Science, Bulletin, v. 65, p. 153–167.
- Voigt, S. and Lucas, S.G., 2017. Early Permian tetrapod footprints from central New Mexico. New Mexico Museum of Natural History and Science, Bulletin, v. 77, p.333–352.
- Voigt, S., Lucas, S.G. 2018. Outline of a Permian tetrapod footprint ichnostratigraphy. Geological Society London, Special Publications, v. 450, p. 387–404.
- Wahlman, G. P., 2019. Pennsylvanian and lower Permian fusulinid biostratigraphy of the Permian basin region, southwestern USA. AAPG Memoir, v. 118, p. 167–227.
- Wahlman, G.P. and King, W.E., 2002. Latest Pennsylvanian and earliest Permian fusulinid biostratigraphy, Robledo Mountains and adjacent ranges, south-central New Mexico: New Mexico Bureau of Geology and Mineral Resources, Circular 208, p. 1–26.
- Wahlman, G.P., Pate, C.R., Rohr, D.M. and Ross, C.A., 2017. Leonardian (Lower Permian) fusulinids from the Cibolo Formation, Chinati Mountains, Presidio County, Texas, USA. Stratigraphy, v. 14, p. 425–441.
- Wardlaw, B.R. and Nestell, M.K., 2019. Conodont biostratigraphy of lower Permian (Wolfcampian-Leonardian) stratotype sections of the Glass and Del Norte mountains, West Texas, USA. AAPG Memoir, v. 118, p. 229–249.
- Williams, T.E., 1963. Fusulinidae of the Hueco Group (Lower Permian), Hueco Mountains, Texas. Peabody Museum of Natural History, Yale University, Bulletin, v. 18, 122 pp.
- Williams, T.E., 1966. Permian Fusulinidae of the Franklin Mountains. Journal of Paleontology, v. 40, p. 1142–1156.
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Large Language Models in palynological taxonomy

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Introduction

Artificial Intelligence is becoming an interesting avenue of research in geology. Recently the International Union of Geological Sciences (IUGS) Deep-time Digital Earth (DDE) team, and partners Alibaba Cloud, have begun to develop a large language model for geology known as GeoGPT. The team also wanted to know if large language model methods could augment a traditional taxonomic key. Could a palynologist sitting by their microscope get some help from a Large Language Model (LLM) in determining a species? It turns out that palynology very much lends itself to developing a professional LLM that might be very useful in teaching taxonomy to apprentice palynologists, or to professionals in environments that require expertise in many areas of palynology. It could also have particular use in Global South countries where access to reference materials may be difficult.

LLM-aided taxonomy is text based, and will probably be delivered through a series of structured questions and answers

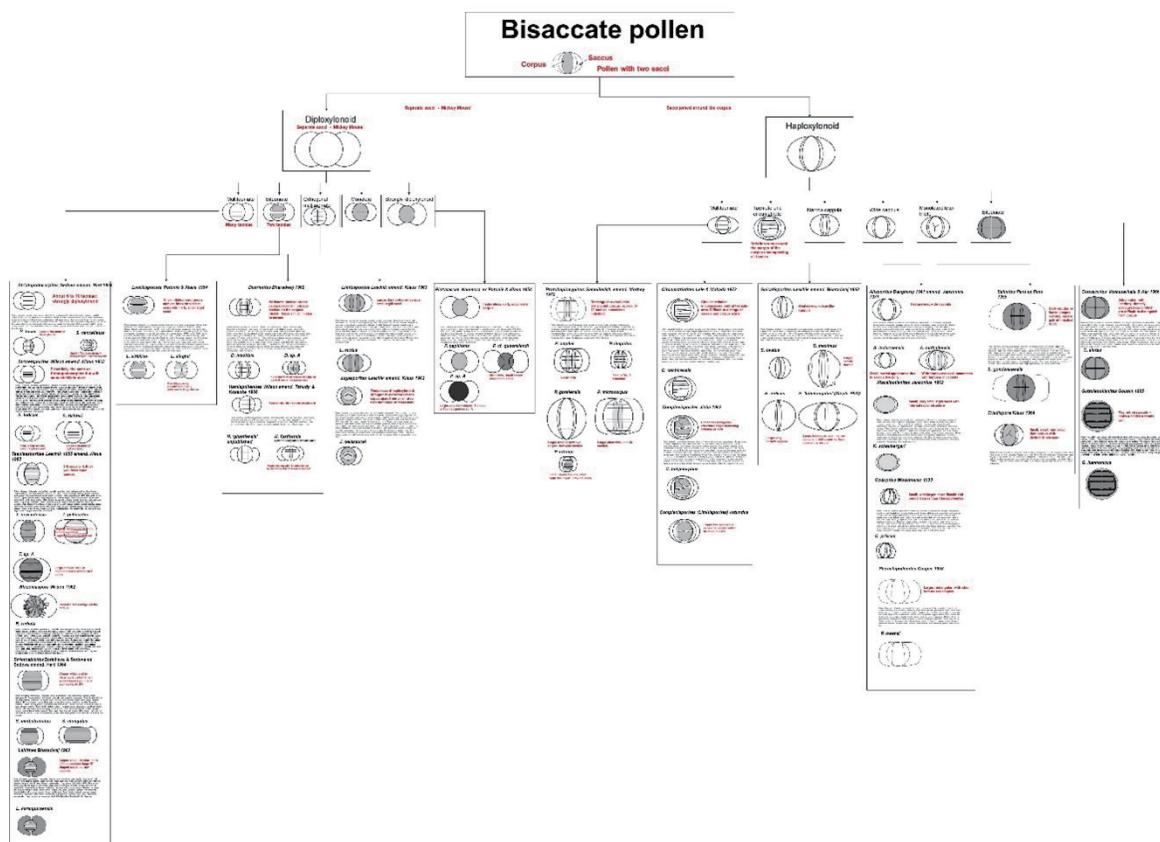


Fig. 1. A taxonomic key for bisaccate pollen.

that converge on a determination, rather than being based on image recognition. There are already some quite sophisticated image-based methods of identification in palynology (e.g. Mahmood et al., 2023; Chronosurveys, 2024; Barnes et al., 2023). However a text-based system could have some big advantages over an image-recognition system.

Taxonomic keys

In palaeontology, an identification key or taxonomic key can be in the form of a printed series of notes and instructions that help you identify a palynomorph (or any fossil), perhaps at genus or species level. Identification keys are also used in many other scientific and technical fields to identify or diagnose diseases, minerals, or archaeological artifacts.

Most keys provide a fixed sequence of identification steps, each with multiple alternatives, the choice of which determines the next step (Fig. 1). When the key stage has two alternatives, the stage is dichotomous, when there are more choices, the stage in the key is polytomous.

At each step, the user has to make a choice about the characters of the fossil being identified. In palynology there are a range of possible starting points and so the person using the key has to know something about the morphology of the range of palynomorphs that might be encountered.

Palynological taxonomy

Discussions with specialists in LLMs have shown that palynology and other newer branches of the science of

palaeontology may have some special advantages for the development of LLMs because they can provide ‘learning materials’ that are clearly and consistently structured. The hierarchical structure of descriptions of palynological species also provide signposts for the LLM in developing the order of questions.

So what might an LLM-aided taxonomic key look like? Well perhaps the system might ask the palynologist a series of questions like: what is the shape of the palynomorph and what is its size? In other words, the LLM key would ask a series of relevant intelligent questions in a particular order, prompting the user to make sensible taxonomic decisions getting closer and closer to a determination. This imitates the traditional key, only a computer is asking the questions. The value of this method over identification using images (e.g. Mahmood et al. 2023) is that the taxonomist is guided through a series of steps that help them understand how taxonomy works. In other words, it is not a ‘black box’.

Imagine if the LLM key was helping you identify a car that you had seen in a car park. It might ask, what's the badge on the car? what's the shape of the headlight, how many headlights does the car have? What is the shape of the radiator grill? After a series of relevant intelligent questions and ‘taxonomic’ decisions you might arrive at an answer at ‘species level’ – so the car is perhaps identified as a Tesla Model S. The same might be true of the palynological taxonomy LLM.

As previously suggested, palynology lends itself to an LLM because the ‘learning materials’ are clearly and consistently

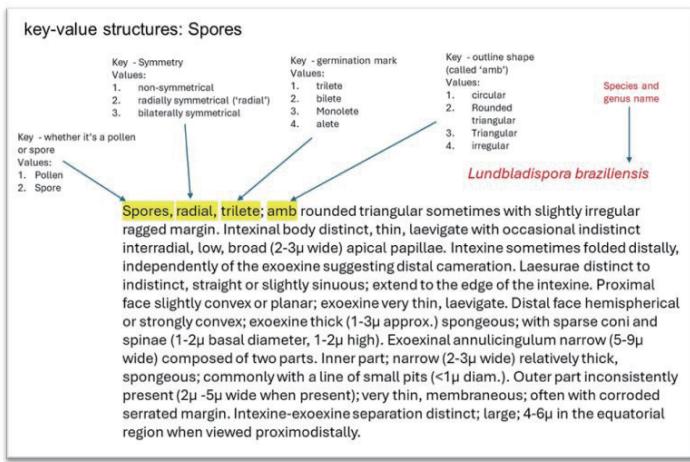


Fig. 2. A set of ‘keys’ and ‘values’ for a species of spore.

structured. What we mean by this is that palynology, being a relatively young branch of palaeontology, is ‘written down’ in a fairly consistent way, i.e. the descriptions and diagnoses of its species are generally consistent in form. This is because most of the descriptions and diagnoses have been written in the last few decades, rather than over a century or more, as is the case with older branches of palaeontology. Mostly nomenclature has remained consistent because descriptive terms mean the same as they have always meant – and measurements are in consistent units. Another advantage is that palynological descriptions and ‘diagnoses’ are remarkably similar in structure and content. Mostly descriptions follow a particular pattern. For example for a spore, the description may begin ‘spores, radial, trilete; amb circular; laesurae distinct, with narrow lips’. For a pollen grain (in this case a monosaccate pollen grain), it might begin ‘pollen, monosaccate, radially symmetrical, trilete; amb circular’. The description goes on to become more detailed. But in a way, the description is offering a hierarchy, in the sense that it begins with the big elements (things like shape and symmetry), and then delves deeper. So as ‘learning material’ for the LLM, it has a built-in step by step process.

Looking deeper, you can analyse each species description in terms of ‘keys’ and ‘values’. Keys are character types, and values are the descriptors, the adjectives. Figs 2 and 3 show a set of ‘keys’ and ‘values’ for a species of saccate pollen and a spore. The keys are signposts for parts of the decision tree, and the values are possible ‘answers’ (like in a drop down menu). Some keys will have a limited number of ‘values’; other keys will have values that are more variable and descriptive with a very large number of possible ‘answers’, and perhaps will need to accommodate continuous variation or subtle shades of difference. For these keys it would be very difficult and restrictive to apply a small number of value ‘choices’.

Taxonomic keys are not perfect because they depend on the knowledge or judgment of the person that designed them. They also depend on the quality of the descriptions and diagnoses, but once an appropriate description structure (as in Figs. 2 and 3) is created, the LLM will do the rest of the work assuming that

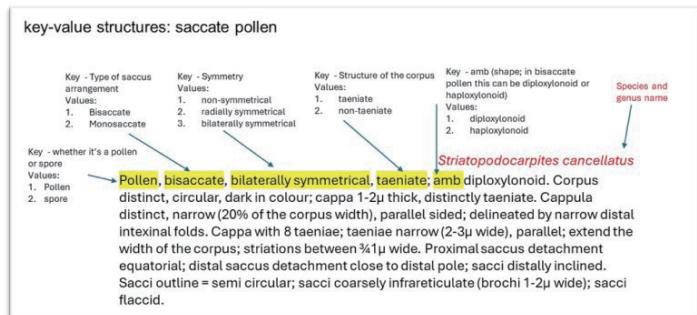


Fig. 3. A set of ‘keys’ and ‘values’ for a species of bisaccate pollen.

it is given plenty of high quality material to ‘learn’ with. In the cases above, the descriptions are from Mike Stephenson’s PhD thesis – and these are not ‘official’ diagnoses or descriptions (i.e. those of the original authors), and they could be flawed. Much more material will be needed (perhaps descriptions of thousands of species), from other PhD theses and databases, and eventually from the peer reviewed literature, so permissions and approvals will have to be gained. Even with these shortcomings, taxonomic keys could be used in teaching and learning, helping students to quickly gain a grasp of the basics of taxonomy. They could be particularly useful in the Global South where even now information is hard to come by (e.g. Nobes and Harris 2019).

Could an LLM-guided taxonomic key be even better than a manual key? Whatever the answer to that question, a traditional or LLM key should not replace the need for students to use taxonomic literature (for example published diagnoses and descriptions). But the use of a well-designed LLM key would have considerable pedagogic value. In a commercial environment, for example in companies that use stratigraphic palynologists, LLM-guided keys could help in standardising taxonomic procedures making taxonomy more reliable and therefore correlation and stratigraphy more reliable.

Research is continuing and it is hoped that a pilot system will be released soon for testing.

References

- Barnes, C.M., Power, A.L., Barber, D.G., Tennant, R.K., Jones, R.T., Lee, G.R., Hatton, J., Elliott, A., Zaragoza-Castells, J., Haley, S.M., Summers, H.D., Doan, M., Carpenter, A.E., Rees, P. and Love, J., 2023. Deductive automated pollen classification in environmental samples via exploratory deep learning and imaging flow cytometry. *New Phytol.*, v. 240, p. 1305–1326. <https://doi.org/10.1111/nph.19186>
- Chronosurveys, 2024. <https://www.chronosurveys.com/research/>
- Mahmood, T., Choi, J. and Ryoung P.K., 2023. Artificial intelligence-based classification of pollen grains using attention-guided pollen features aggregation network, *Journal of King Saud University - Computer and Information Sciences*, v. 35, p. 740–756.
- Nobes, A. and Harris, S., 2019. Open Access in developing countries – attitudes and experiences of researchers. <https://doi.org/10.5281/zenodo.3464868>

The Rotliegend fauna of the Thuringian Forest Basin – a compendium

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"Die Rotliegend-Fauna des Thüringer Waldes" is the title of a special hard cover edition of the museum journal Semana of the Natural History Museum Schloss Bertholdsburg in Schleusingen, Thuringia (Germany), edited by R. Werneburg and J.W. Schneider. In it, 18 authors describe all fossil animal groups with all their species and genera known to date from the continental Upper Pennsylvanian and the Permian of the Thuringian Forest Basin. The book comprises 272 pages and is well illustrated with 567 figures. Written in German, the book is primarily aimed at the numerous amateur palaeontologists and private collectors who have contributed so much to our current knowledge with their fossil finds and information. It is of course also written for palaeontologists, and the extensive English captions (here somewhat shortened) make it worth reading, even for non-native German speakers.

The first chapter (Schneider et al.) is devoted to the regional geology and stratigraphy of this region (Figs. 1, 2), the understanding of which began with medieval mining. The

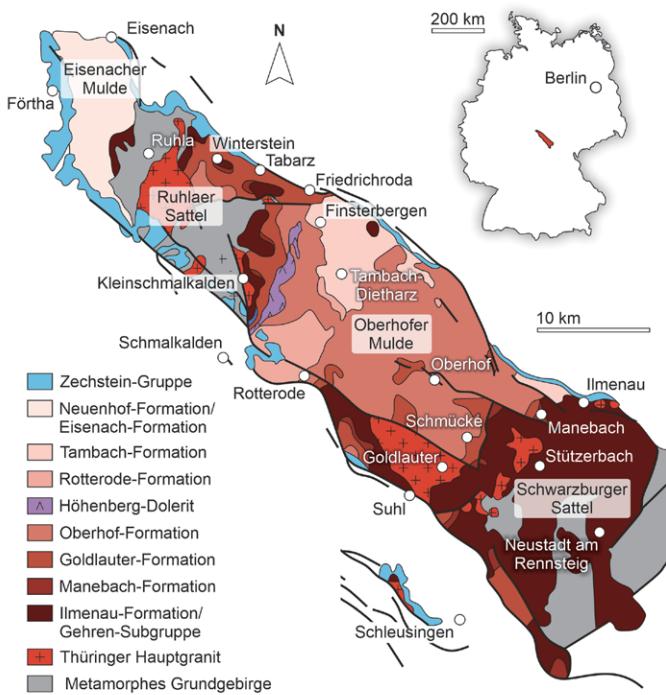


Fig. 1. Geological map of the Thuringian Forest; modified from Lützner et al. (2012) and Trümper et al. (2019).

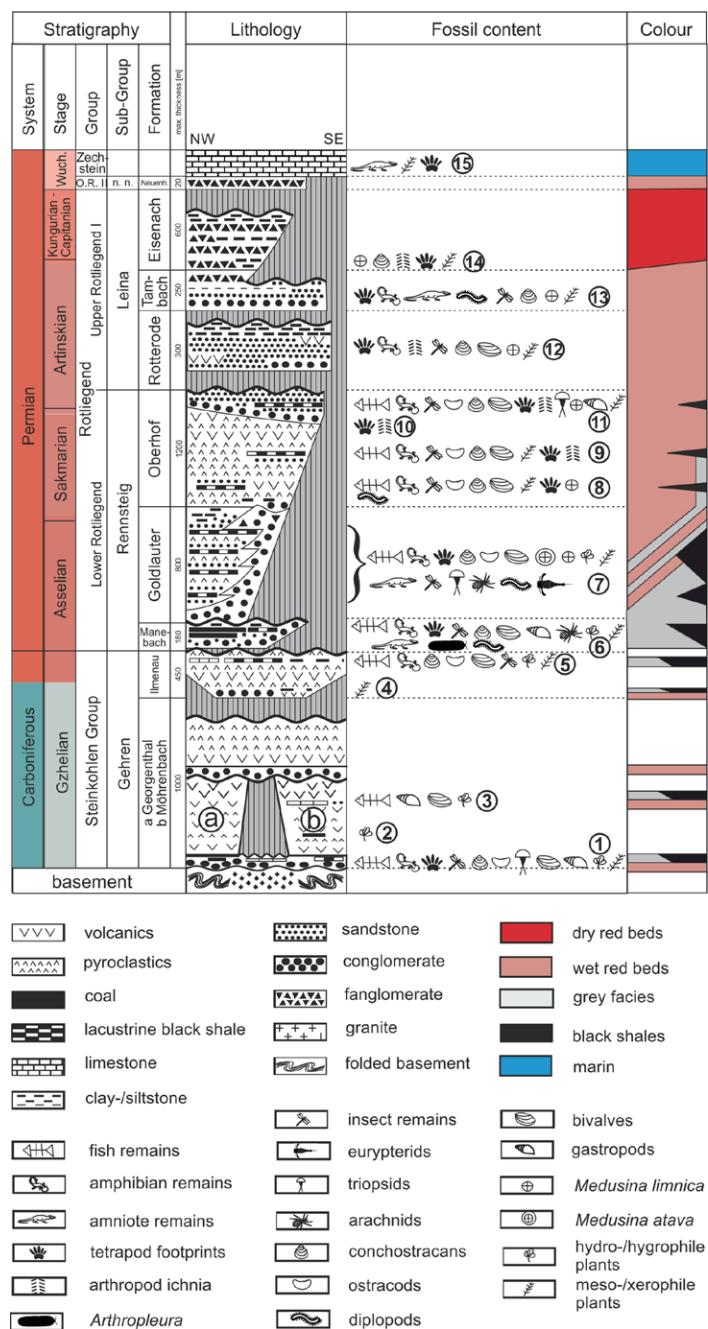


Fig. 2. Stratigraphy, lithology and fossil record of the Upper Carboniferous and the Permian of the Thuringian Forest Basin. After Schneider et al. (2019), Lithostratigraphy after Andreas (1996, 2014), Chronostratigraphy after Schneider et al. (2020).

first description of (plant) fossils goes back to Mylius (1709). The monographs by Schlotheim (1804, 1820) on fossil plants from the Lower Permian (Lower Rotliegend) of the Thuringian Forest are internationally recognised as the birth of scientific palaeobotany. Animal fossils, insect wings, were first described by Heer (1864) and Goldenberg (1869). The first tetrapod track was mentioned by Cotta (1848). Tetrapod tracks from the Bromacker fossil Lagerstätte near Tambach-Dietharz, which has since become famous for the joint occurrence of tracks and the skeletons of their producers, were first published by Pabst (1895). Since the mid-seventies of the last century, around 50

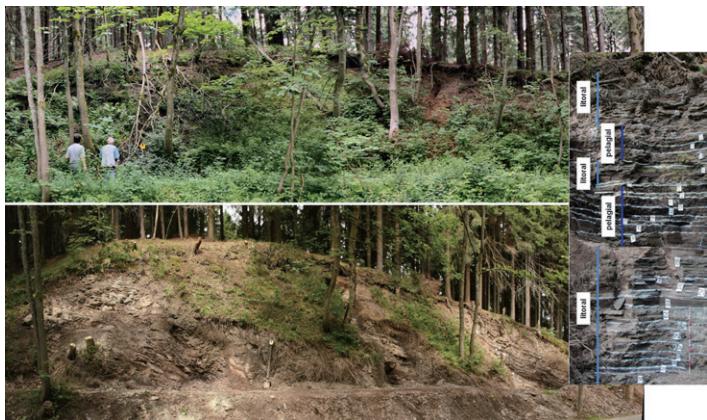


Fig. 3. Geotope of the Lower Protriton Horizon of the Lower Oberhof Fm. at Lochbrunnen near Oberhof town; **a** – view before the excavation 2012; **b** – restored geotope 2012; **c** – example of high-resolution sedimentological and palaeontological documentation showing frequent changes between littoral and pelagic facies in a shallow lake of the branchiosaurian type.



Fig. 4. Excavation team of 2012 to study and restore the Geotope Lochbrunnen near Oberhof; colleagues from the Natural History Museum Schloss Bertholdsburg, Schleusingen, and students, PhD students and staff of the TU Bergakademie Freiberg.

targeted excavations for fossil-bearing horizons have been carried out almost every year in the Thuringian Forest in cooperation between the Museum Schleusingen with the Technical University Bergakademie Freiberg (Figs. 3, 4).

The second chapter (Scholze, Schneider and Voigt) is devoted to hydromedusae, the third to bivalves and microconchids as well as to the extremely rare (because of a taphonomical bias) gastropods (Scholze & Schneider). The fourth chapter presents the arachnids (Rößler). These include the stratigraphically youngest finds of trigonotarbrids and probably the oldest evidence of a true spider (Araneae) (Fig. 5). Eurypterids and euthycarcinoids are described in chapter 5 (Schneider and Werneburg). Some eurypterids changed from marine to freshwater during the Devonian. They are not uncommon in the continental Pennsylvanian throughout the Euramerican region. In the Carboniferous/Permian transition of Carrizo Arroyo, New Mexico, they are still very common in coastal freshwater ponds. In the Permian, Artinskian, they are only known in the Elmo Insect Beds of Kansas. All the more surprising are the ca. 40 finds of *Adelophtalmus* in the Asselian of the Thuringian Forest (Fig. 6). The discovery of *Euthycarcinus martensi* in red beds

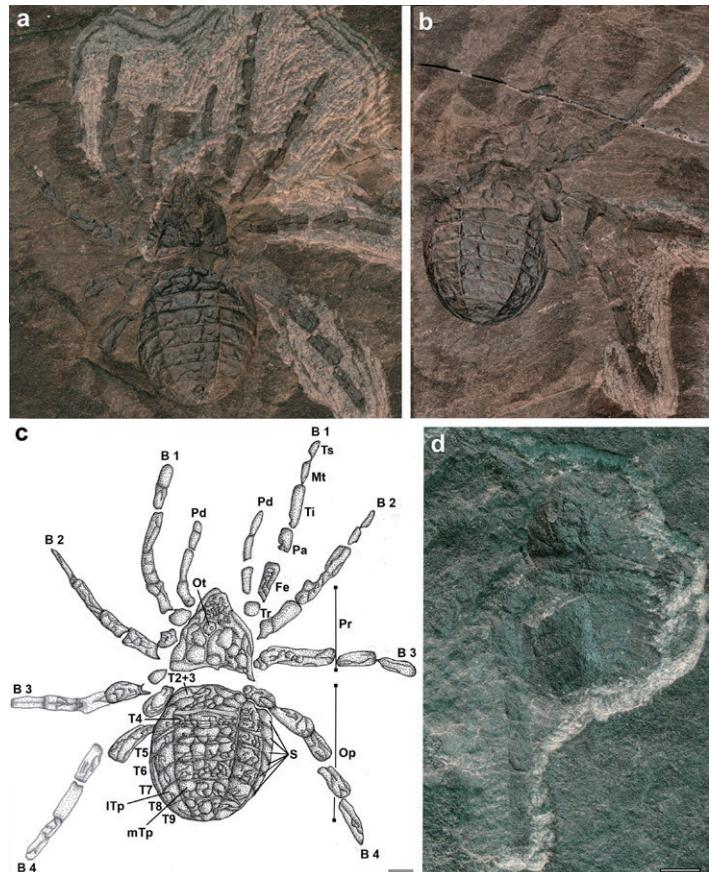


Fig. 5. Arachnids of the Thuringian Forest Permian; Sperbersbach site, Goldlauter Fm. **a** - *Aphantomartus areolatus* (Pocock, 1911), NHMS-Am2863; **b** - Counterpart of NHMS-Am2863; **c** - Interpretative drawing of NHMS-Am2863; **d** - *Aphantomartus* cf. *areolatus*. Op: opisthosoma; Pr: prosoma; B 1–IV: legs; Tr: trochanter; Fe: femur; Pa: patella; Ti: tibia; Mt: metatarsus; Ts: tarsus; Pd: pedipalps; S: sternites; T: tergites; IP: lateral tergite plate; mP: median tergite plate; scale bars: 1 mm.

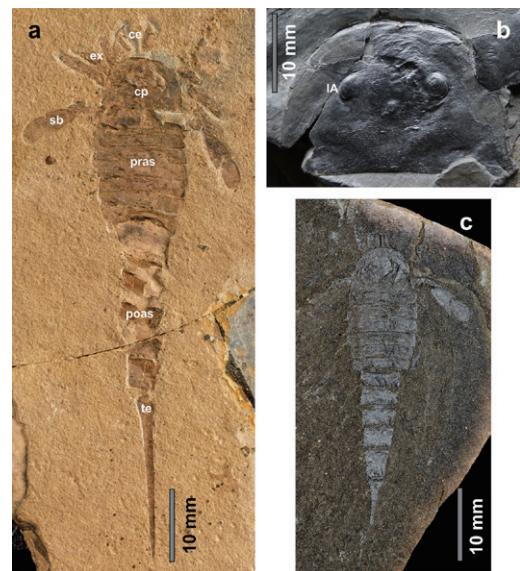


Fig. 6. *Adelophtalmus* sp. from the Lower Goldlauter Fm. (Lower Permian, Asselian), Sperbersbach site, Thuringian Forest; **a** - best preserved specimen, NHMS-Am 5212a; **b** - largest prosoma from a reconstructed c. 19 cm long individual, NHMS-Am 3865a; **c** - one of the smallest specimens, c. 5 cm long, NHMS-Am 2975a. ce - pincer-like chelicerae, ex - extremities, cp - carapax, IA - lateral eyes, sb - swimming legs, pras - praebdominal segments, poas - postabdominal segments, te - telson.

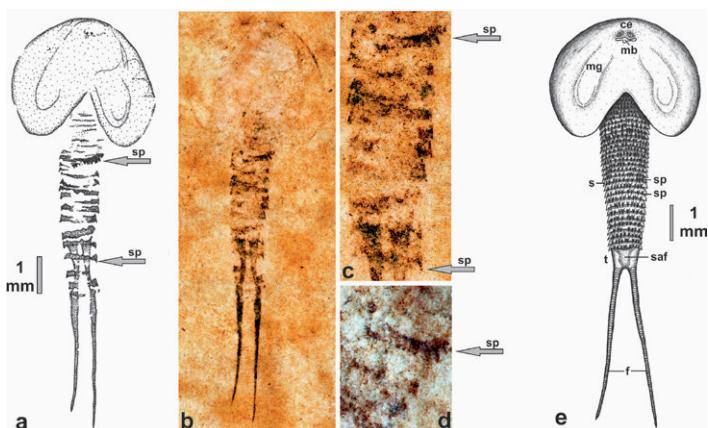


Fig. 7. The kazacharthraiid *Thuringiops nephroides* from the Upper Oberhof Formation (Rotliegend, Sakmarian, Lower Permian) of Friedrichroda; **a-d** - holotype FG 299/2/153-2, with spines on segments; **e** – reconstruction.



Fig. 9. The iconic invertebrate trace *Tambia spiralis* from the Tambach Fm. (BGR Berlin- Spandau, BGR P453/1).

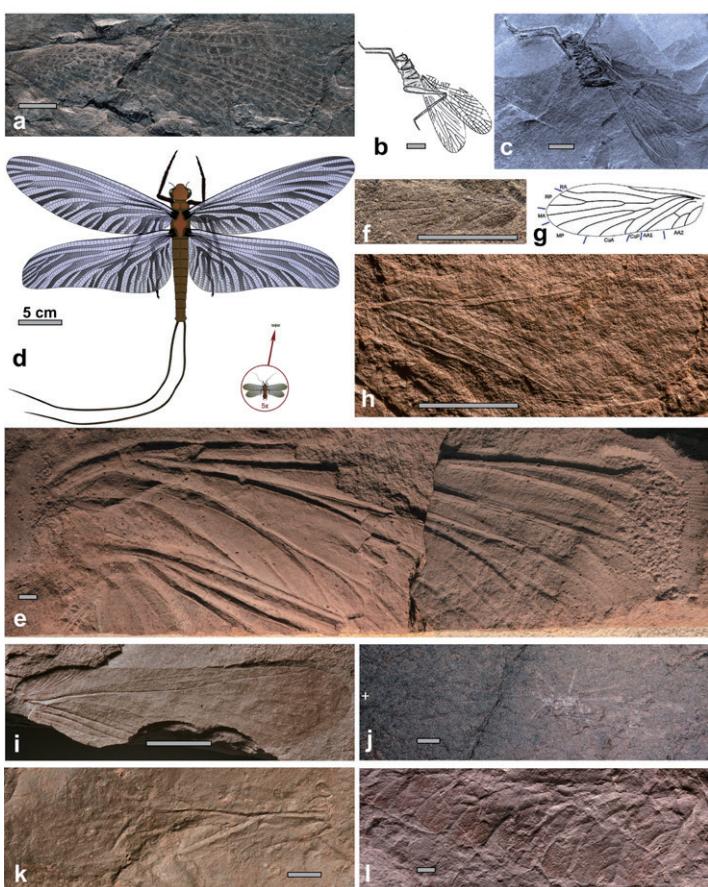


Fig. 8. Insects from the Lower Permian of the Thuringian Forest Basin. Scale bar in **d** 5 cm, all other scale bars 5 mm. **a** – *Macrophlebiium hollebeni* GOLDENBERG, 1869, holotype, MMG: ThP 438, Manebach, Manebach Fm.; **b**, **c** – *Thueringoedischia trostheidei* ZESSIN, 1997, holotype, Naturkundemuseum Leipzig, Cabarz, Lower Goldlauter Fm.; **d**, **e** – Syntoopteroid, Cabarz, Lower Goldlauter Fm., **d** – reconstruction of the giant insect, inserted the reconstruction of the smallest insect from Cabarz so far, a miomoptere with 0.55 cm wing length (see **f**, **g**), in the same scale and five times magnified; **e** – the approx. 21 cm long forewing, MNG 8208a,b; **f**, **g** - Miomoptera, probably *Delopsocus* TILLYARD, 1928, Cabarz, Lower Goldlauter Fm.; **h** – overlapping Ephemeroptera forewings, Cabarz, Lower Goldlauter Fm., NHMS-WP 4797; **i** – Orthopteran *Thueringoedischia* sp., Cabarz, Lower Goldlauter Fm., NHMS-WP 6146; **j** – completely preserved caloneurid insect, the cross marks the end of the ca. 4 cm long antennae, Cabarz, Lower Goldlauter Fm., NHMS-WP12139; **k** – forewing of a caloneurid, Bromacker, Tambach Fm., MNG 11336; **l** – forewing of a paoliid, Bromacker, Tambach Fm., MNG 11348-2.

of the Oberhof Formation unfortunately remains the only record in the continental Permian of Euramerica to date. The common invertebrate trace fossil *Striatichnium natalis* may have been created by a euthycarcinoid. Chapter 6 deals with arthropleurids and myriapods (Schneider and Werneburg). The *Arthropleura* finds from the Manebach Formation, earliest Asselian, were used to reconstruct an animal measuring around 2.30 metres. This gigantic size was confirmed by trackway finds from El Cobre Canyon, New Mexico. While the spined archipolipods typical of the Pennsylvanian have not yet been found anywhere, diplopods are not uncommon in grey and red facies. But their classification is made very difficult by the incomplete preservation. However, they played an important role in the Permian ecosystem as detritivores. The popular tadpole shrimps are discussed in chapter 7 (Werneburg and Schneider). They are represented by kazacharthrauids and triopsids (Fig. 7). Apparently during the Late Pennsylvanian and Early Permian they changed their favoured habitat from perennial lakes of the lacustrine grey facies to seasonal water accumulations of the red facies as demonstrated in the Thuringian Forest Basin. The very common conchostracans and ostracods are dealt with in chapter 8 (Scholze and Schneider). The Carboniferous/Permian profile of the Thuringian Forest and the Permian/Triassic transitional sections of the present-day Thuringian Basin served as the basis for the development of a conchostracean biostratigraphy of this period in Euramerica. Ostracods are very common and form an important part of the food webs. Unfortunately, the generally poor preservation of the primarily feature-poor freshwater ostracods does not allow an exact classification. Syncarid shrimps are described in chapter 9 (Germann & Schneider). They are represented by the widely distributed (in Europe) *Uronectes fimbriatus* and *Palaeocaris secretanae*. Insects are very common, especially cockroaches, which are discussed in chapter 10 (Schneider and Brauner). About 3,000 finds of more than ten orders have been discovered, particularly as a result of the scientific excavations carried out in the last few decades. This large number of finds and the high

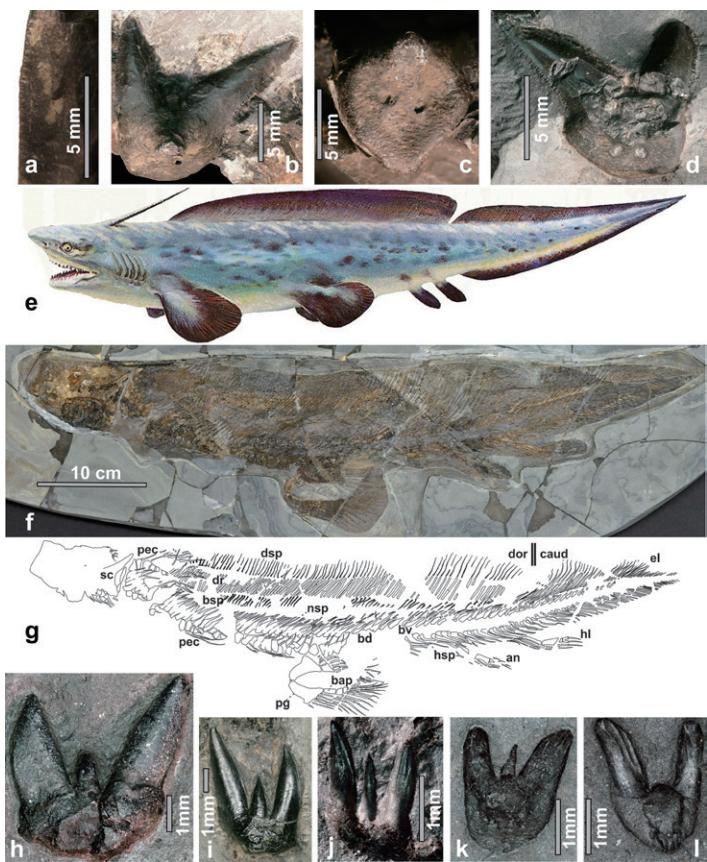


Fig. 10. Xenacanthiform sharks of the Thuringian Forest Basin: *Orthacanthus* (a-d), *Xenacanthus* (e, h, i) and *Bohemiacanthus* (f, g, j-l). **a** - double crenulated lateral cusp edge of the holotype to *Orthacanthus carbonarius* (Germar, 1844), Wettin Subformation, Saale Basin, MLU 1095; **b**, **c** - *O. carbonarius*, Möhrenbach Fm., NHMS-2002, **b** - labial, **c** - basal; **d** - the same, NHMS-Am 11167, labiobasal, well visible the double crenulation; **e** - reconstruction of *Xenacanthus decheni* with the typical fins supported by ceratotrichia bundles, (after Spinar & Burian, 1973); **f**, **g** - *Bohemiacanthus carinatus*, Manebach Fm., NHMS-WP 1608; **h**, **i** - *Xenacanthus* teeth with the typical non-crenulated lateral edges, Manebach Fm.; **h** - Manebach lake horizon NHMS-WP 2761, **i** - Manebach, NHMS-Am 13500; **j-l** - *Bohemiacanthus* teeth with the typical labial and lingual cristae, **j** - *Bohemiacanthus* type U-ge, Möhrenbach Fm., NHMS-Am 11171a; **k** (labial) - **l** (lingual) - *B. carinatus*, imprints, Manebach lake horizon, NHMS-WP 2770.

diversity make especially the Sperbersbach and Cabarz localities the world's most important sites of Lower Permian (lower Asselian) entomofaunas (Fig. 8). Invertebrate tracks, mainly produced by arthropods, are particularly widespread in the red beds of the higher Lower Rotliegend as discussed in chapter 11 (Walter, Voigt and Scholze) (Fig. 9). Interesting animal-plant interactions are reported in chapter 12 (Laaß and Rößler). Of particular interest, in addition to various damage types on plant leaves, are wood boring galleries. As shown in chapter 13 (Schneider & Puschmann), cartilaginous fishes are represented by 6 genera of Hybodontiformes and Xenacanthiformes as well as *Acanthodes*. This chapter also corrects some taxonomic errors, in particular concerning the genera *Orthacanthus*, *Triodus* and *Bohemiacanthus* and their species (Fig. 10). Chapter 14 (Vogel and Kogan) reports on the common but yet poorly studied bony fishes. Much remains to be done in this area. Amphibians are represented by 26 species from 17 genera and 12 families, as

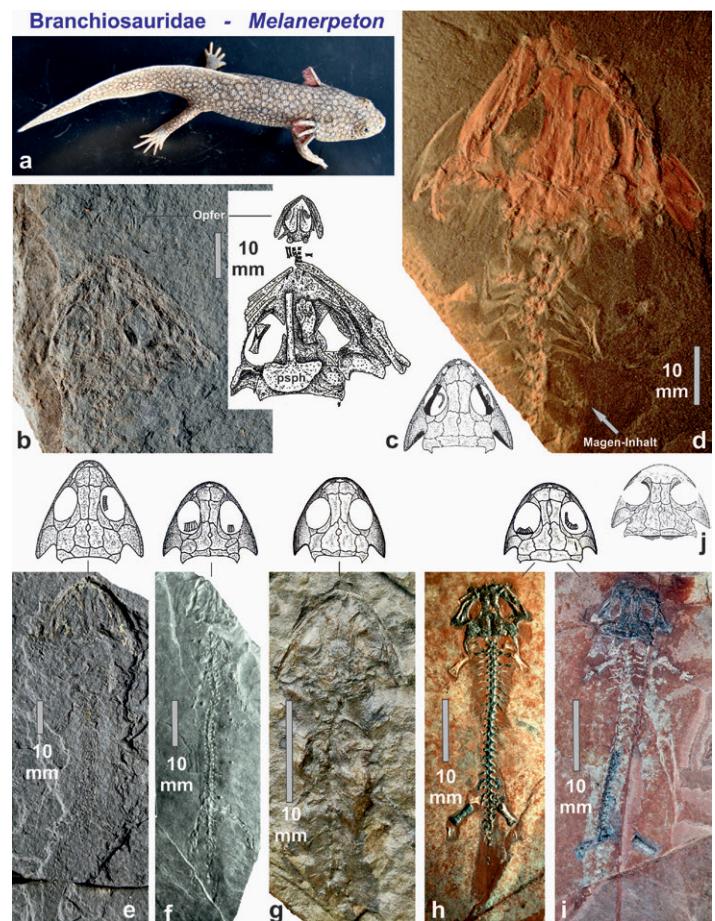


Fig. 11. The branchiosaurids *Melanerpeton*, *Xerodromeus* and *Schoenfelderpeton*; **a** - live reconstruction of *Leptorhynchus/Melanerpeton*; **b** - *M. sembachense* with conspecific larva in the stomach - cannibalism, (NHMS-WP216), Ilmenau Fm.; **c-d** - *M. eisfeldi* (**c** - skull reconstruction, **d** - with stomach contents, SSF-A291) Upper Goldlauter Fm.; **e** - *M. sembachense* (NHMS-WP9922); **f** - *M. eisfeldi* (MNG 5331-99); **g** - *M. arnhardti*, both Lower Oberhof Fm.; **h-i** - *Xerodromeus gracilis* (**h** - FG 299/2/43a, **i** - NHMS-WP563), Upper Oberhof Fm.; **i** - *Schoenfelderpeton prescheri* (skull reconstruction after FG 321/10/17a, b) Lower Goldlauter Fm.

chapter 15 (Werneburg) shows. High numbers of finds and high diversity make the Thuringian Forest profile one of the hotspots for Late Palaeozoic amphibians in Euramerica (Fig. 11). Consequently, the amphibian biostratigraphy of the European Permian basins is mainly based on the sequence of species in this profile. The amniotes, although rare in the Thuringian Forest so far, are presented in chapter 16 (Spindler). In addition to the famous skeletal finds from the Bromacker fossil Lagerstätte with the oldest bipedal reptiles, reference is made to stratigraphically older, albeit rare, finds such as the facultative bipedal varanopid *Cabarzia* (Fig. 12). The Permian Rotliegend of the Thuringian Forest is one of the regions where the first tetrapod tracks were found. Since the middle of the 19th century, around 6,000 tetrapod tracks from 170 localities have been stored in museums here. An overview of this is provided in chapter 17 (Voigt). Chapter 18, Palaeoecology (Schneider et al.), provides the synthesis of the investigated excavation profiles, their sedimentology, fossil content and taphonomy. Starting from the oldest fossil-bearing horizon in the Upper Pennsylvanian Möhrenbach Formation.

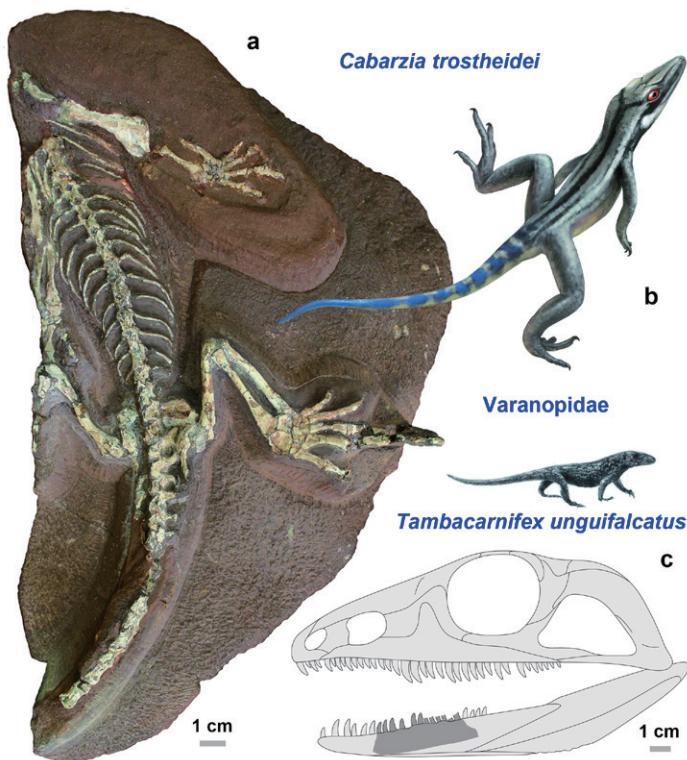


Fig. 12. Varanopidae from the Thuringian Forest Basin; **a** – *Cabarzia trostheidei*, Goldlauter Fm., NML-G2017/001 (holotype); **b** – life restoration of the same as the geologically oldest known biped; **c** – *Tambacarnifex unguifalcatus* (quadrupedal varanopid) from the Tambach Fm., MNG 15037, fragment of mandible (dark grey) inserted into skull reconstruction of the close relative *Varanops*.

(Stephanian C, Gzhelian) to the youngest fossil occurrences in the Eisenach Formation of the late Early Permian (Cisuralian, Kungurian), food pyramids were designed for each level. This was done both for the aquatic faunas and, as far as possible, also for the terrestrial ecosystems (Fig. 13). The summarising chapter 19 (Schneider et al.) underlines the role of the Thuringian Forest profile as a reference section for the European latest Pennsylvanian and the Early to Middle Permian. The Upper Permian is represented by only a few decametre continental red beds and the transgressive marine Zechstein. The continuous Permian/Triassic transition is exposed in fossiliferous sections of the present-day Thuringian Basin north of the Thuringian Forest Mountains. The extensive and detailed stratigraphical, sedimentological and palaeontological investigations in this Upper Pennsylvanian to lowermost Triassic sections allow correlation of this local information by the use of biostratigraphic and radioisotopic age data with the other European and non-European basins (Fig. 14). In synthesis, conclusions can be drawn between interactions of geotectonic processes, such as orogenesis and magmatism, and global climate development and their influence on the evolution of biota and ecosystems in Europe (Fig. 15).

For references see: Werneburg, R. and Schneider, J.W. (eds.), 2024. Rotliegend-Fauna des Thüringer Waldes.

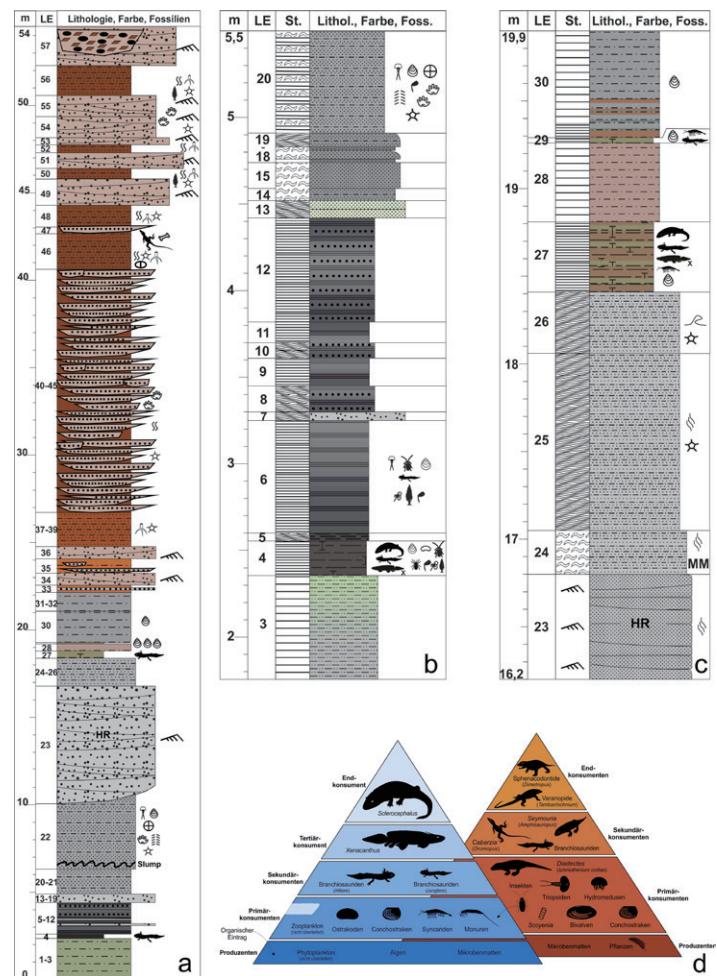


Fig. 13. Sections of the Lower Goldlauter Fm. in the Cabarz quarry. **a** – composite normal profile; HR – main channel; **b** – detail section: fluvio-lacustrine siltstones of LE 3 are followed by the black shale amphibian lake horizon of LE 4 to LE 6; the fossil-rich LE 20 belongs to the floodplain deposits LE 20 to 22 in **a**; **c** – detail section: approx. 1.6 m above the main channel sandstone (LE 23) the laminated, amphibian-bearing limestone of LE 27 (Fig. 13c) and approx. 45 cm above this a 3 cm thick conchostracans bearing limestone (LE 29). MM – microbial mats structures. Legend s. Fig. 2. **d** - Trophic pyramid of the two Cabarz lake horizons; they are amphibian-dominated, actinopterygians are absent probably due to frequent oxygen deficiency, xenacanthids appeared only sporadically, top predators are large amphibians; the trophic pyramid of the flood plains consist of aquatic elements of temporary ponds and poodles as well as of terrestrial elements such as insects and the tetrapods, the latter known mainly only from their tracks.

Sonderveröffentlichung Semana, 272 p., 567 figs.

This book with its extensive bibliography is a compendium of more than 200 years of geological and palaeontological research in one of the key regions of the European Permian. It can be ordered for 29 € (plus postage) from the following address: info@museum-schleusingen.de.

It is supplemented by the second edition of the revision of the flora of the Thuringian Forest: Barthel, M. (2022): Die Rotliegendflora des Thüringer Waldes. Sonderveröffentlichung Semana, 202 p., 310 figs. It can also be ordered from the same address as above for 27 € (plus postage).

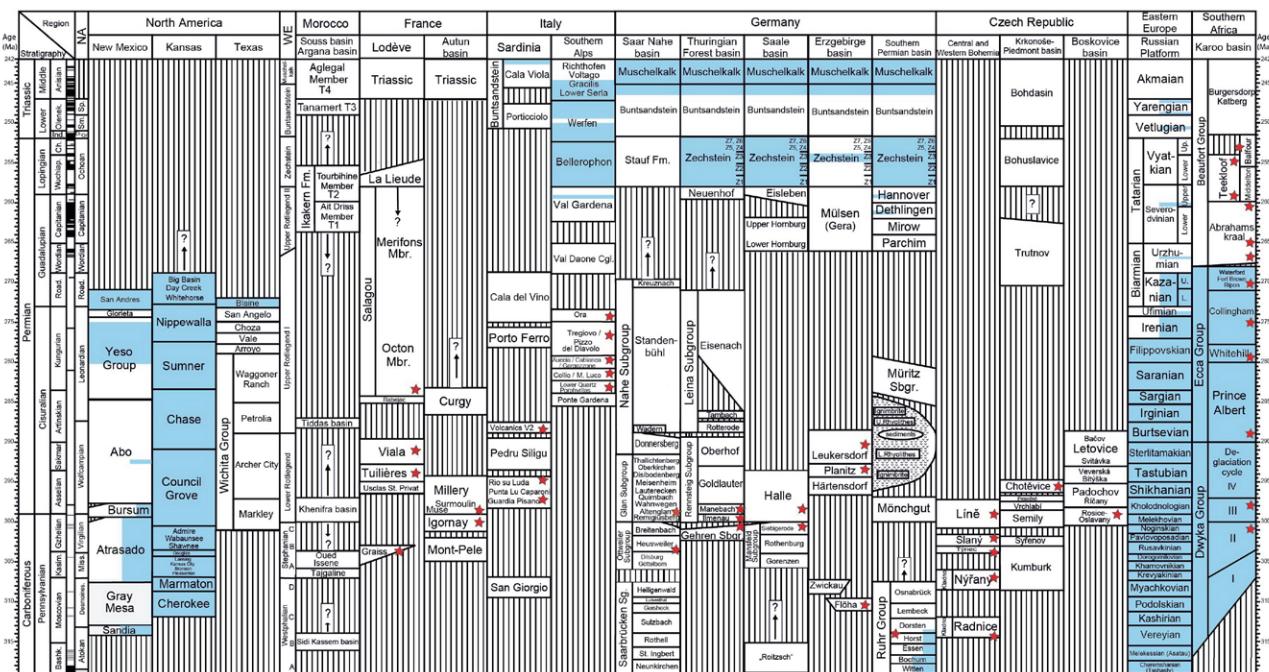


Fig. 14. Multistratigraphic correlation of the most important Euramerican basins with each other and with the profiles of the Russian Platform and South Africa. Radioisotopic ages are marked with red stars. For detailed information and references see Schneider et al. (2020) and Werneburg & Schneider (2024). Marine deposits are marked in blue. Abbreviations: NA - North American regional scale; WE - Western European regional scale; Miss. - Missourian; Road. - Roadian; Gr. - Griesbachian; Di. - Dienerian; Sm. - Smithian; Sp. - Spathian; Cant. - Cantabrian; Graiss. - Graissessac; Cgl. - Conglomerate; Kreuzn. - Kreuznach. From Schneider et al. (2020, fig. 2) supplemented with new data.

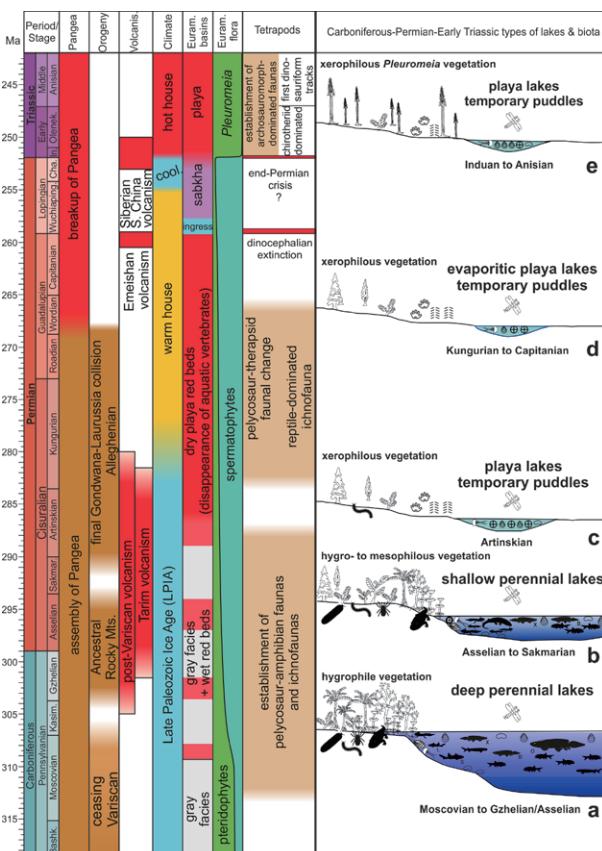


Fig. 15. Synopsis of significant global and regional processes of geotectonics, paleoclimate, depositional environments and biota as well as schematically the sequence of lake types in Central Europe during the Late Carboniferous to the Middle Triassic (a – e). "Ingress." marks the Zechstein ingress in Central Europe and the Bellerophon transgression of the Southern Alps. From Schneider et al., 2020, fig. 19, modified and completed.

Evidence of Wuchiapingian (Late Permian) climate cooling: seasonal changes revealed by brachiopod shell sclerochemistry

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The Permian Period has been the theatre of some of the most dramatic environmental and climatic changes in Earth's history. It transitioned from a glacial world at the start of the period to a hothouse culminating in the end-Permian mass extinction, through a series of changes that are yet to be fully constrained. As a result, the Permian community has been working intensively with the aim to understand and resolve these changes at the highest resolution possible. One aspect still debated revolves around a cooling phase in the early Wuchiapingian which is thought to have resulted from the emplacement and subsequent weathering of the Emeishan Large Igneous Province (LIP) in South China (e.g. Huang et al., 2022). The Emeishan LIP has also been linked to the end-Guadalupian mass extinction (e.g. Bond and Wignall, 2014; Rampino et al., 2024). While several lines of evidence support a climatic cooling at the start of the Wuchiapingian, its duration and magnitude remains questionable (e.g. Wang et al., 2020; Cheng et al., 2022; Sun et al., 2022). One of the most complete records of the Guadalupian-Lopingian time interval is represented by the sedimentary successions in Iran, which are rich in fossil brachiopods, known as reliable archives of palaeoclimatic proxies (e.g. Brand et al., 2011; Garbelli et al., 2022). We thus selected brachiopod shells belonging to *Araxilevis intermedius* (Abich, 1878) from the Julfa and Abadeh sections in North and Central Iran, deposited at low palaeolatitudes (Ghaderi et al., 2014; Viaretti et al., 2021), to try to reconstruct the climate conditions at the beginning of the Late Permian. The species *A. intermedius* is characterized by a large sized and thick shell (Fig. 1), representing an ideal target for sclerochemical analyses to reconstruct palaeoclimate conditions. We selected the specimens from correlatable beds of the two sections following the brachiopod biozones proposed by Viaretti et al. (2021) (Fig. 2). To constrain the duration of the cooling phase, we investigated the seasonal seawater variations recorded in the *A. intermedius* shells, as the intensity of seasonal temperature variations can be considered a good proxy of cold versus warm climate conditions (e.g. Ivany et al., 2000; Steuber et al., 2005; Crippa et al., 2016). The selected shells were screened for diagenetic alteration using SEM, cathodoluminescence, trace elements and EBSD analyses. From these analyses some shell portions were found to be altered; however, these altered portions were limited in extent and the shells overall preservation was deemed to be good and suitable for geochemical analyses. The samples collected from the altered portions of the shells or close to fractures were excluded from the interpretation. The shells were sampled for stable isotopes sclerochemistry ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) collecting powders at high resolution along the axis of maximum growth, and the palaeotemperatures recorded by the brachiopods were calculated using the equation of Brand et al. (2019). The $\delta^{18}\text{O}$

profiles measured on the shells at the base of the successions have high variability spanning across the field of equilibrium (Fig. 3). Conversely, shells at the top of the successions recorded very limited variation in their $\delta^{18}\text{O}$ values (Fig. 3), and since $\delta^{18}\text{O}$ is a proxy for palaeotemperatures these results correspond to palaeotemperature variations. If compared to seasonal variations currently experienced at similar low palaeolatitudes and settings, e.g. Palau (Colin and Johnston, 2020) or the central Indian Ocean (Diaz et al., 2023), the $\delta^{18}\text{O}$ values recorded by the shells of *A. intermedius* indicate an increased amplitude of seasonality of temperature in the *Clarkina asymmetrica* Zone at the base of both sections, suggesting cool climate conditions in this interval. The palaeotemperature seasonality recorded by brachiopods then decreases in amplitude upward returning to the expected seasonal variation of $\sim 3^\circ\text{C}$ in the *Clarkina transcaucasica* Zone, indicating the end of the cooling phase between 257 and 256 Ma. Our results indicate that the cooling phase most likely had a short duration, lasting about two million of years (Fig. 4). A short duration of the cooling phase agrees with some other studies that are based on different proxies (e.g. Chen et al., 2011; Sun et al., 2022), whereas other studies have suggested a longer phase (e.g. Wang et al., 2020). Interestingly, shell size, microstructural elements and biodiversity indices do not change through this cooling phase, indicating that brachiopods were quite resilient to the observed climate change.

This work will be shortly submitted to the special issue Biocalcifier resilience and response during global climate changes in Palaeogeography, Palaeoclimatology, Palaeoecology (Guest Editors C. Bottini & G. Crippa), and has been performed with the collaboration of Dr. Gaia Crippa and Prof. Giovanna Della Porta from the University of Milano (IT), Prof. Renato Posenato and Dr. Valentina Brombin from the University of Ferrara (IT), Dr. Hana Jurikova from the University of St. Andrews (UK) and Dr. Erika Griesshaber from the University of Munich (DE).

References

- Bond D.P.G. and Wignall P.B., 2014. Large igneous provinces and mass extinctions: An update. In Keller G. and Kerr A.C. (eds), Volcanism, Impacts, and Mass Extinctions: Causes and Effects. Geological Society of America Special Paper, v. 505, p. 29–55.
- Brand U., Logan A., Bitner M.A., Griesshaber E., Azmy K. and Buhl D., 2011. What is the ideal proxy of Palaeozoic seawater chemistry? Memoirs of the Association of Australasian Palaeontologists, v. 41, p. 9–24.
- Brand U., Bitner M.A., Logan A., Azmy K., Crippa G., Angiolini L., Colin P., Griesshaber E., Harper E.M., Taddei Ruggiero E. and Haussermann V., 2019. Brachiopod-based oxygen-isotope thermometer: update and review. Rivista Italiana di Paleontologia e Stratigrafia, v. 125, n. 3, p. 775–778.
- Chen B., Joachimski M.M., Sun Y., Shen S. and Lai X., 2011. Carbon and conodont apatite oxygen isotope records of Guadalupian–Lopingian boundary sections: climatic or sea-level signal? Palaeogeography, Palaeoclimatology, Palaeoecology, v. 311, n. 3–4, p. 145–153.
- Cheng C., Wang X., Li S., Cao T., Chu Y., Wei X., Li M., Wang D. and Jiang X., 2022. Chemical weathering indices on

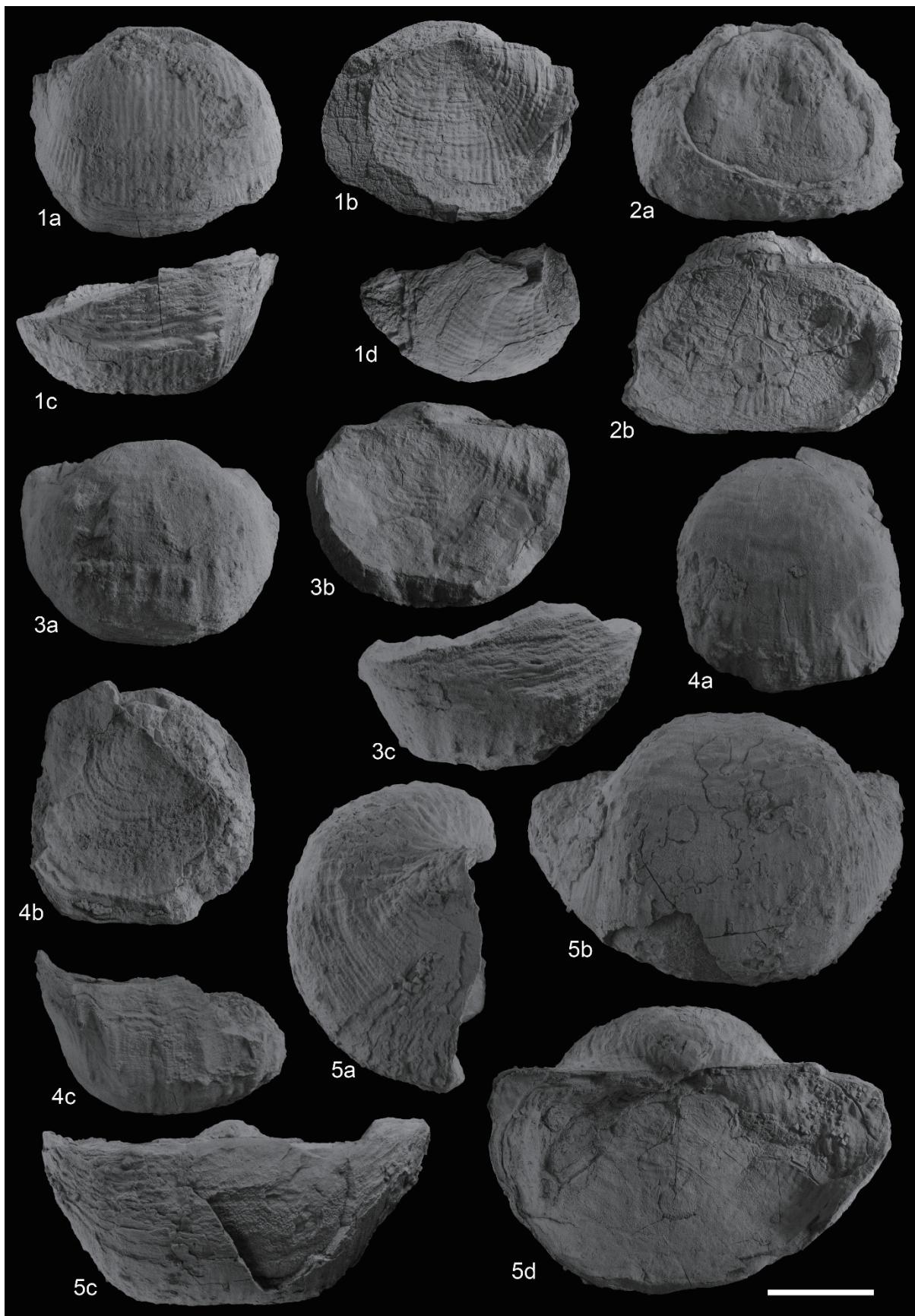


Fig. 1. *Araxilevis intermedius* from the Abadeh section, Central Iran. From Viaretti et al. (2021).

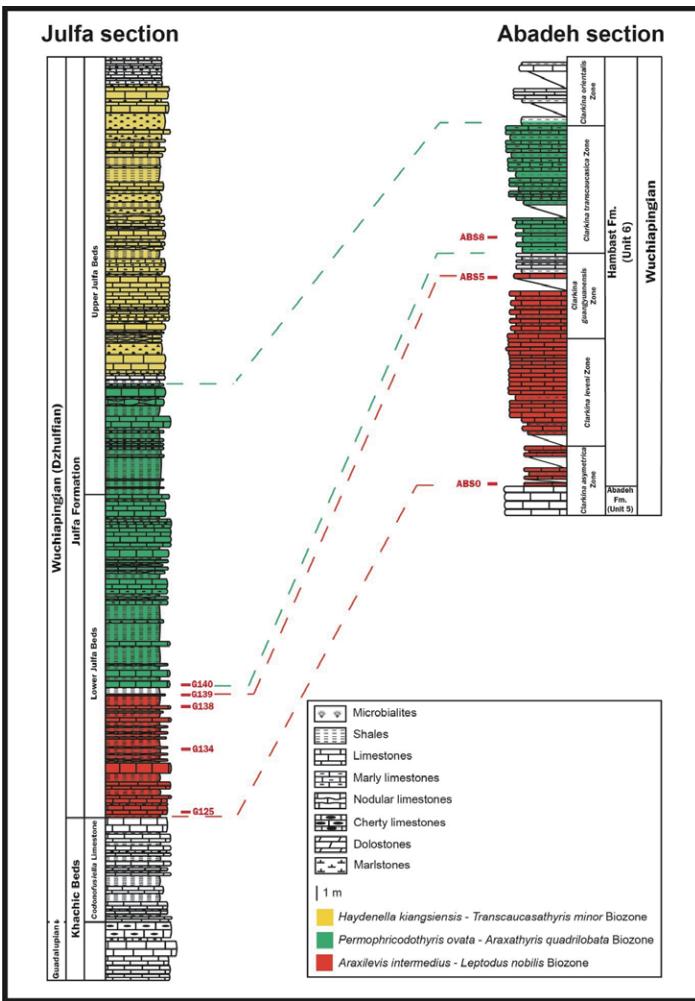


Fig. 2. Stratigraphic beds from which the *A. intermedius* shells were selected. Modified from Viaretti et al. (2021).

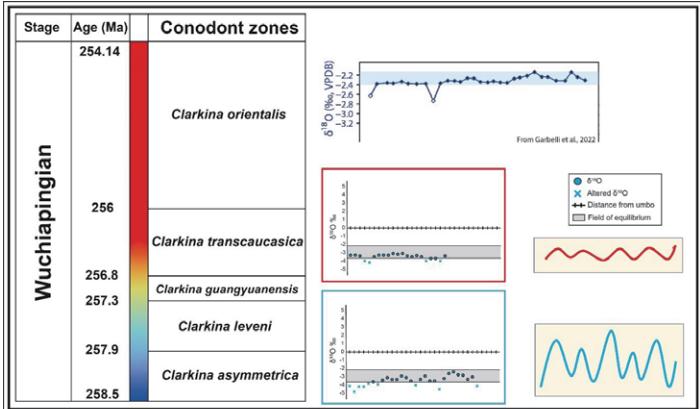


Fig. 3: $\delta^{18}\text{O}$ profiles measured on *A. intermedius* shells. The plots are in stratigraphic order, showcasing the reduction in palaeotemperature seasonality. The data from Garbelli et al. (2022) measured on stratigraphically younger brachiopods are in agreement with a short duration of the cooling phase.

marine detrital sediments from a low-latitude Capitanian to Wuchiapingian carbonate-dominated succession and their paleoclimate significance. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 606, p. 111248.

Colin P.L. and Johnston T.S., 2020. Measuring temperature in coral reef environments: Experience, lessons, and results from

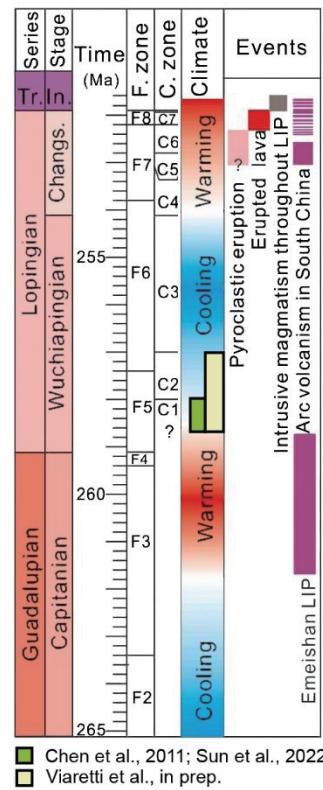


Fig. 4. Compilation of the duration of the Wuchiapingian cooling phase. Cooling and warming intervals and events from Wang et al (2020).

Palau. Journal of Marine Science and Engineering, v. 8, n. 9, p. 680.

Crippa G., Angiolini L., Bottini C., Erba E., Felletti F., Frigerio C., Hennissen J.A.I., Leng M.J., Petrizzo M.R., Raffi I., Rainieri G. and Stephenson M.H., 2016. Seasonality fluctuations recorded in fossil bivalves during the early Pleistocene: Implications for climate change. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 446, p. 234–251.

Diaz C., Foster N.L., Attrill M.J., Bolton A., Ganderton P., Howell K.L., Robinson E. and Hosegood P., 2023. Mesophotic coral bleaching associated with changes in thermocline depth. Nature Communications, v. 14, n. 1, p. 6528.

Garbelli C., Angiolini L., Posenato R., Harper E.M., Lamare M.D., Shi G.R. and Shen S.Z., 2022. Isotopic time-series ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) obtained from the columnar layer of Permian brachiopod shells are a reliable archive of seasonal variations. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 607, p. 111264.

Ghaderi A., Garbelli C., Angiolini L., Ashouri A.R., Korn D., Rettori R. and Gharaie M.H.M., 2014. Faunal change near the end-Permian extinction: the brachiopods of the Ali Bashi Mountains, NW Iran. Rivista Italiana di Paleontologia e Stratigrafia, v. 120, n. 1, p. 27–59.

Huang H., Huyskens M.H., Yin Q.Z., Cawood P.A., Hou M., Yang J., Xiong F., Du Y. and Yang C., 2022. Eruptive tempo of Emeishan large igneous province, southwestern China and northern Vietnam: Relations to biotic crises and paleoclimate changes around the Guadalupian-Lopingian boundary. Geology, v. 50, n. 9, p. 1083–1087.

- Ivany L.C., Patterson W.P. and Lohmann K.C., 2000. Cooler winters as a possible cause of mass extinctions at the Eocene/Oligocene boundary. *Nature*, v. 407, n. 6806, p. 887–890.
- Rampino M.R. and Shen S.Z., 2019. The end-Guadalupian (259.8 Ma) biodiversity crisis: the sixth major mass extinction? *Historical Biology*, v. 33, n. 5, p. 716–722.
- Steuber T., Rauch M., Masse J.P., Graaf J. and Malkoč M., 2005. Low-latitude seasonality of Cretaceous temperatures in warm and cold episodes. *Nature*, v. 437, n. 7063, p. 1341–1344.
- Sun S., Chen A., Hou M., Yang S., Ogg J.G., Zou H., Xu S., Li Q., Huang Y., Li R. and Chen H., 2022. Rapid climatic fluctuations during the Guadalupian-Lopingian transition: Implications from weathering indices recorded in acid-insoluble residues of carbonate rocks, South China. *Journal of Asian Earth Sciences*, v. 230, p. 105222.
- Viaretti M., Crippa G., Posenato R., Shen S.Z. and Angiolini L., 2021. Lopingian brachiopods from the Abadeh section (Central Iran) and their biostratigraphic implications. *Bollettino della Società Paleontologica Italiana*, v. 60, n. 3, p. 213–254.
- Wang W.Q., Garbelli C., Zhang F.F., Zheng Q.F., Zhang Y.C., Yuan D.X., Shi Y.K., Chen B. and Shen S.Z., 2020. A high-resolution Middle to Late Permian paleotemperature curve reconstructed using oxygen isotopes of well-preserved brachiopod shells. *Earth and Planetary Science Letters*, v. 540, p. 116245.

Publication summary: Latest Permian and earliest Triassic geomagnetic polarity timescale: A polarity reversal marks the greatest mass extinction

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Compilation of the geomagnetic polarity scale

The establishment of the geomagnetic polarity time scale for the latest Permian has been inhibited by the inconsistent polarity patterns published by different teams for the section at Meishan (Li and Wang, 1989; Liu et al., 1999; Meng et al., 2000; Zhang et al., 2021), which hosts the Global Boundary Stratotype Section and Points (GSSPs) for the Permian-Triassic boundary (PTB) and base of the underlying Changhsingian Stage (Yin et al., 2001; Jin et al., 2006). We have analyzed the magnetostratigraphy of the Shangsi section, the former candidate for the PTB GSSP (Lai et al., 1996), and the alternate Chaotian section (Isozaki et al., 2007) in South China to compile a composite magnetostratigraphy calibrated to conodont zones of the Changhsingian to earliest Triassic of South China (Chen et al., 2024, summarized here). This geomagnetic polarity succession was correlated using conodont zones and other criteria to other published magnetostratigraphic studies to compile a reliable geomagnetic polarity time scale spanning the late Wuchiapingian and Changhsingian to early Induan (Fig. 1).

The upper Wuchiapingian to lower Changhsingian is dominated by normal polarity (chron "LP2n" of Hounslow and Balabanov, 2018) with three reversed-polarity subchrons (LP2n.0r to LP2n.2r) within the *Clarkina wangii* conodont Zone (Yuan et al., 2019). The mid to upper Changhsingian is dominated by reversed polarity, with the onset of the chron "LP2r" in the *C. changxingensis* Zone (Yuan et al., 2019). The biostratigraphic placement of the brief normal-polarity chron "LP3n" of the upper Changhsingian is within the *C. yini* Zone. The reversed-polarity chron "LP3r" of the uppermost Changhsingian (upper *C. yini* to *C. meishanensis* Zones, Yuan et al., 2019) is succeeded by the normal-polarity chron "LT1n" that spans from the very uppermost Changhsingian into the lower Griesbachian substage of the basal Triassic (Lai et al., 2018).

Age model for the geomagnetic polarity scale

The Milankovitch cyclostratigraphy interpretations of Wu et al. (2013) were adopted to project a floating astronomical time scale (ATS) from the latest Wuchiapingian to the earliest Induan onto the Shangsi geomagnetic polarity pattern, using data from this and three previous studies (Heller et al., 1988; Steiner et al., 1989; Glen et al., 2009). We anchored the ATS

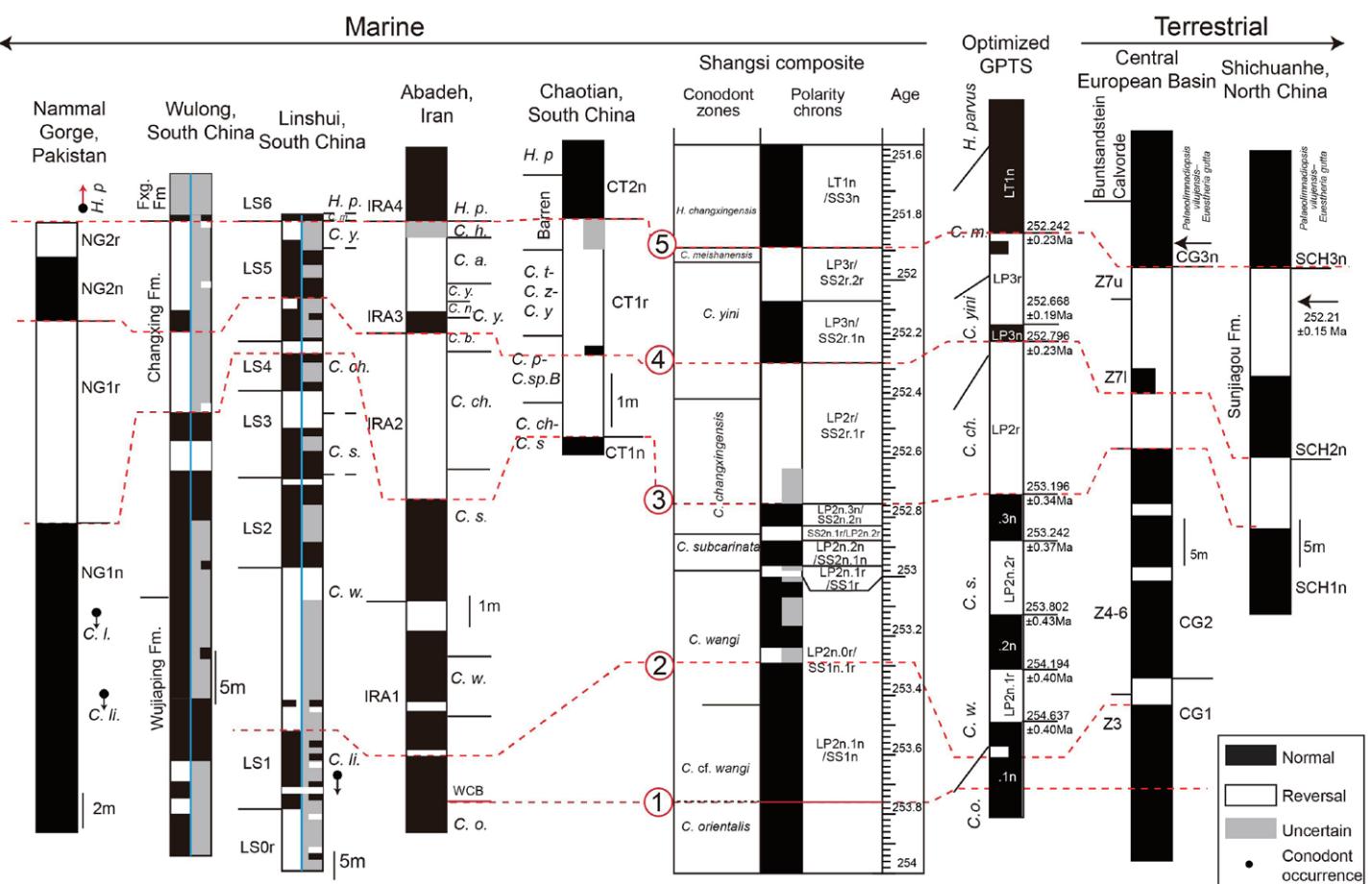


Fig. 1. Proposed correlation of our composite astronomical cycle-tuned geomagnetic polarity time scale with conodont zones from the Shangsi section of South China with other magnetostratigraphic studies of marine and terrestrial Changhsingian sections. Datasets: (1) Nammal Gorge: geomagnetic polarity pattern from Haag and Heller (1991); conodont occurrences are projected from the same regional study (Waterhouse, 2010). (2, 3) Wulong and Linshui sections: geomagnetic polarity patterns from Heller et al. (1995) with the right sub-columns after graying out intervals that had low-quality-rated samples; conodont zones are modified projections from the adjacent Daijiagou section (Yuan et al., 2015). (4) Abadeh section: geomagnetic polarity pattern from Gallet et al. (2000), conodont zones proposed by Shen and Mei (2010) with estimated WCB placement by Liu et al. (2013), revised *H. parvus* Zone placement by Horacek et al. (2021). (5, 6) Chaotian and Shangsi sections: references see main text. (7) Optimized GPTS, adopted from Hounslow (2016). (8) Central European Basin: geomagnetic polarity pattern from Soffel and Wippern, (1998); Szuradies (2013); (9) Shichuanhe, North China: geomagnetic polarity pattern from Guo et al. (2022). Conodont species abbreviations: *C. l.* = *Clarkina longicuspisata*; *C. w.* = *Clarkina wangii*; *C. li.* = *Clarkina liangshanensis*; *C. s.* = *Clarkina subcarinata*; *C. ch.* = *Clarkina changxingensis*; *C. y.* = *Clarkina yini*; *C. m.* = *Clarkina meishanensis*; *C. a.* = *Clarkina abadehensis*; *C. h.* = *Clarkina hauschkei*; *C. n.* = *Clarkina nodosa*; *C. b.* = *Clarkina bachmanni*; *H. c.* = *Hindeodus changxingensis*; *H. p.* = *Hindeodus parvus*.

on Bed 27 at the Shangsi section which correlates to Bed 25 at Meishan section, dated as 251.941 ± 0.037 Ma (radioisotopic date using EARTHTIME tracer calibration; Burgess et al., 2014). The anchored ATS in Meishan suggested the FAD of *C. wangii* at the GSSP for the base of the Changhsingian Stage (WCB) is 253.76 Ma (Yuan et al., 2019). This is nearly identical (within the limits of uncertainty) to the FO of *C. cf. wangii* at 253.82 Ma at Shangsi in this study, and within the offset between pre- and EARTHTIME calibrations radioisotopic dates (Hounslow, 2016).

High-resolution integrated time scale for the Permian-Triassic boundary interval

The integration of conodont biozones, carbon isotope excursions and the revised magnetostratigraphy composite from the Shangsi (Jiang et al., 2011; Shen et al., 2013; Yuan et al., 2019) and Chaotian (Ji et al., 2007; Wu et al., 2022) sections produces a high-resolution consistent sequence of the latest Permian mass extinction (LPME), the onset of chron LT1n and then the PTB; thereby enabling high-resolution global correlation

of these latest Permian to earliest Triassic events (Fig. 2).

The base of the major normal-polarity chron LT1n coincides with the lowest occurrence of conodont *H. changxingensis* at Shangsi, which is just after the onset of the latest Permian mass extinction in South China and slightly prior to the PTB (Jiang et al., 2007, 2011; Lai et al., 2018), and continues into the lower part of the Griesbachian substage. The integrated bio-chemo-magnetostratigraphy studies from a variety of marine and terrestrial paleoenvironments reveal a general agreement that the normal-polarity chron LT1n began after the onset of the LPME and prior to the PTB (beginning of the Triassic) (Fig. 2). Therefore, the base of LT1n is an important marker for recognizing the LPME and the PTB in non-fossiliferous successions and enabling high-precision temporal correlation of the LPME levels.

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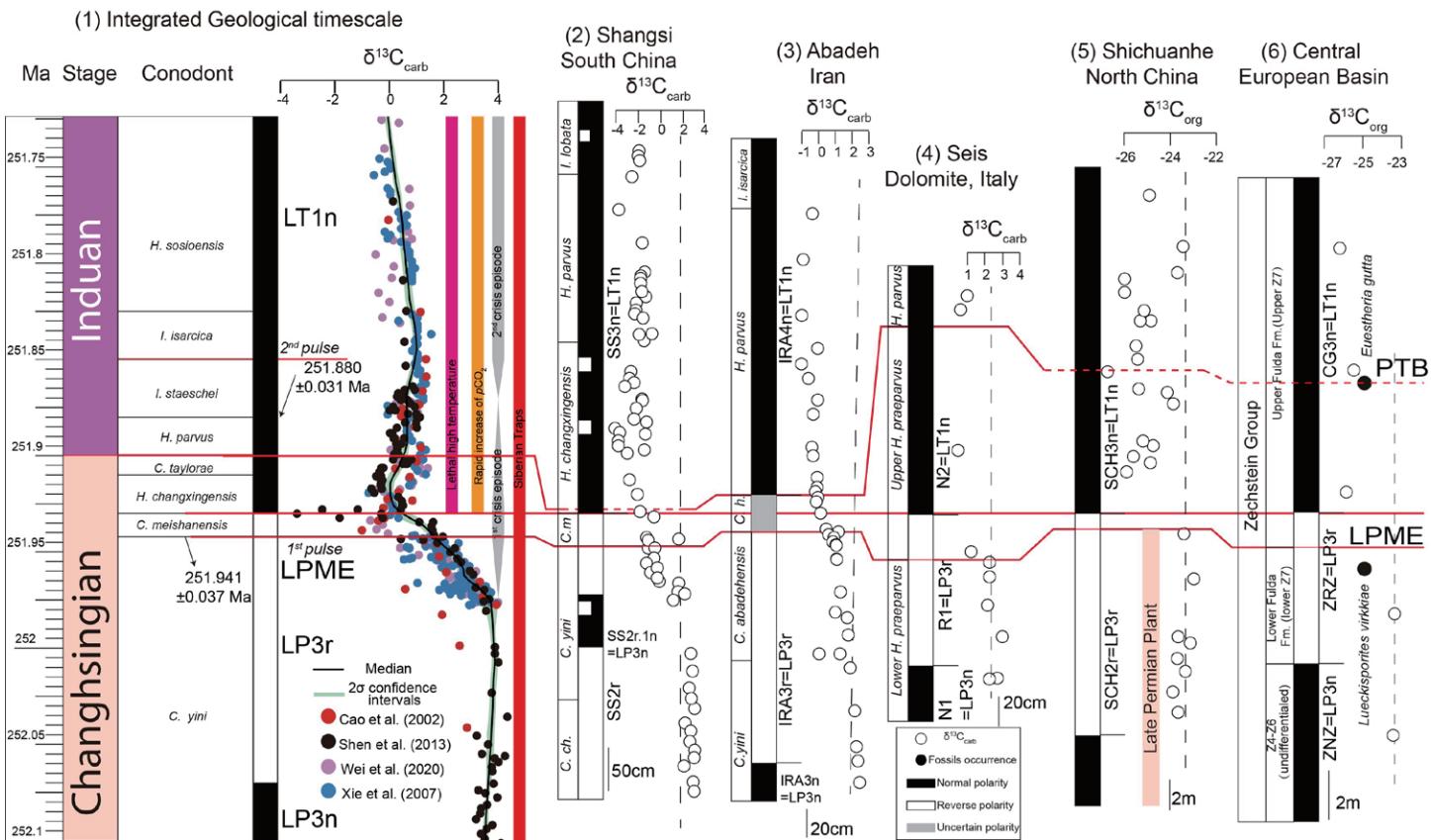


Fig. 2. Placements of carbon-isotope shifts, the latest Permian mass extinction (LPME) and Permian-Triassic boundary (PTB) levels from selected global reference sections in various depositional environments relative to the magnetostratigraphy in the integrated geological timescale of this study. The level of LPME is indicated as the lowest red line. The level of the base of polarity chron LT1n is indicated by the continuous horizontal red line. The level of the estimated PTB is indicated by the upper red line. Datasets: (1) Integrated Geologic Time Scale – age scale is the astronomical time scale (ATS) at Shangsi and Meishan (Wu et al., 2013) anchored to the radioisotopic dates from Meishan (Burgess et al., 2014); conodont biozones from Lai et al. (2018); geomagnetic polarity pattern is from this study; $\delta^{13}\text{C}_{\text{carb}}$ is a composite from several studies (Cao et al., 2002; Xie et al., 2007; Shen et al., 2013; Wei et al., 2020), trend median line of the $\delta^{13}\text{C}_{\text{carb}}$ is a locally weighted smoothing regression (LOWESS, 0.1Myr window) with 2SD confidence intervals, which are calculated using ACycle 2.4.1 (Li et al., 2019). Global trends (colored bars) - lethally high temperature from Joachimski et al. (2012); the increase of atmospheric CO₂ from Shen et al. (2022); two mass extinction pulses from Song et al. (2013) and Yin et al. (2012); Siberian Traps timing from Burgess et al. (2017). (2) Shangsi section, South China - conodont biozones from Jiang et al. (2011) and Yuan et al. (2019); $\delta^{13}\text{C}_{\text{carb}}$ from Shen et al. (2013); geomagnetic polarity pattern from this study. (3) Abadeh section, Iran - conodont biozones from Shen and Mei (2010); geomagnetic polarity pattern from Gallet et al. (2000); $\delta^{13}\text{C}_{\text{carb}}$ from Richoz et al. (2010). (4) Seis, Dolomites, Italy - conodont biozones are projected from nearby sections (Perri and Farabegoli, 2003); geomagnetic polarity pattern from Scholger et al. (2000); $\delta^{13}\text{C}_{\text{carb}}$ from Horacek et al. (2010). (5) Shichuanhe, North China - geomagnetic polarity pattern, estimated PTB and LPME from Guo et al. (2022) and references therein; $\delta^{13}\text{C}_{\text{org}}$ from Wu et al. (2020). (6) Central European Basin: geomagnetic polarity pattern from Szurles (2013) and Scholze et al. (2017); $\delta^{13}\text{C}_{\text{org}}$ and estimated PTB from Scholze et al. (2017).

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References

- Burgess, S.D., Bowring, S. and Shen, S.Z., 2014. High-precision timeline for Earth's most severe extinction. Proceedings of the National Academy of Sciences, v. 111, p. 3316–3321. <https://doi.org/10.1073/pnas.1317692111>
- Burgess, S.D., Muirhead, J.D. and Bowring, S.A., 2017. Initial pulse of Siberian Traps sills as the trigger of the end-Permian mass extinction. Nature Communications, v. 8, p. 164. <https://doi.org/10.1038/s41467-017-00083-9>
- Cao, C.Q., 2002. Carbon isotope excursions across the Permian-Triassic boundary in the Meishan section, Zhejiang Province, China. Chinese Science Bulletin, v. 47, p. 1125–1129. <https://doi.org/10/cd56nf>
- Chen, Y., Jiang, H.S., Ogg, J.G., Wignall, P.B. and Lai, X.L., 2024. Latest Permian and earliest Triassic geomagnetic polarity timescale: A polarity reversal marks the greatest mass extinction Global and Planetary Change, v. 233, p. 104368. <https://doi.org/10.1016/j.gloplacha.2024.104368>
- Gallet, Y., Krystyn, L., Besse, J., Saidi, A. and Ricou, L., 2000. New constraints on the Upper Permian and Lower Triassic geomagnetic polarity timescale from the Abadeh section (central Iran). Journal of Geophysical Research: Solid Earth, v. 105, p. 2805–2815. <https://doi.org/10/drvtnc>
- Glen, J.M.G., Nomade, S., Lyons, J.J., Metcalfe, I., Mundil, R. and Renne, P.R., 2009. Magnetostratigraphic correlations of Permian–Triassic marine-to-terrestrial sections from China. Journal of Asian Earth Sciences, v. 36, p. 521–540. <https://doi.org/10.1016/j.jasearthesci.2008.09.001>

- doi.org/10.1016/j.jseaes.2009.03.003
- Guo, W.W., Tong, J.N., He, Q., Hounslow, M.W., Song, H.J., Dal Corso, J., Wignall, P.B., Ramezani, J., Tian, L. and Chu, D.L., 2022. Late Permian–Middle Triassic magnetostratigraphy in North China and its implications for terrestrial-marine correlations. *Earth and Planetary Science Letters*, v. 585, p. 117519. <https://doi.org/10.1016/j.epsl.2022.117519>
- Haag, M. and Heller, F., 1991. Late Permian to Early Triassic magnetostratigraphy. *Earth and Planetary Science Letters*, v. 107, p. 42–54. <https://doi.org/10/bzgcq2>
- Heller, F., Chen, H.H., Dobson, J. and Haag, M., 1995. Permian–Triassic magnetostratigraphy—new results from South China. *Physics of the Earth and Planetary Interiors*, v. 89, p. 281–295. <https://doi.org/10/bgq8vx>
- Heller, F., Lowrie, W., Li, H.M., L. and Wang J.D., 1988. Magnetostratigraphy of the Permo-Triassic boundary section at Shangsi (Guangyuan, Sichuan Province, China). *Earth and Planetary Science Letters*, v. 88, p. 348–356. [https://doi.org/10.1016/0012-821x\(88\)90091-x](https://doi.org/10.1016/0012-821x(88)90091-x)
- Horacek, M., Krystyn, L. and Baud, A., 2021. Comment to Chen et al., 2020: "Abrupt warming in the latest Permian detected using high resolution in situ oxygen isotopes of conodont apatite from Abadeh, central Iran. *Albertiana*, v. 70, p. 33–36.
- Horacek, M., Povoden, E., Richoz, S. and Brandner, R., 2010. High-resolution carbon isotope changes, litho- and magnetostratigraphy across Permian-Triassic Boundary sections in the Dolomites, N-Italy. New constraints for global correlation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 290, p. 58–64. <https://doi.org/10/c7w68x>
- Hounslow, M.W., 2016. Geomagnetic reversal rates following Palaeozoic superchrons have a fast restart mechanism. *Nature Communications*, v. 7, p. 12507. <https://doi.org/10/ghtm6n>
- Hounslow, M.W. and Balabanov, Y.P., 2018. A geomagnetic polarity timescale for the Permian, calibrated to stage boundaries. Geological Society, London, Special Publications, v. 450, p. 61–103. <https://doi.org/10.1144/SP450.8>
- Isozaki, Y., Shimizu, N., Yao, J.X., Ji, Z.S. and Matsuda, T., 2007. End-Permian extinction and volcanism-induced environmental stress: The Permian–Triassic boundary interval of lower-slope facies at Chaotian, South China. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 252, p. 218–238. <https://doi.org/10.1016/j.palaeo.2006.11.051>
- Ji, Z.S., Yao, J.X., Isozaki, Y., Matsuda, T. and Wu, G.C., 2007. Conodont biostratigraphy across the Permian–Triassic boundary at Chaotian, in Northern Sichuan, China. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 252, p. 39–55. <https://doi.org/10/cc63dk>
- Jiang, H.S., Lai, X.L., Luo, G.M., Aldridge, R., Zhang, K.X. and Wignall, P., 2007. Restudy of conodont zonation and evolution across the P/T boundary at Meishan section, Changxing, Zhejiang, China. *Global and Planetary Change*, v. 55, p. 39–55. <https://doi.org/10.1016/j.gloplacha.2006.06.007>
- Jiang, H.S., Lai, X.L., Yan, C.B., Aldridge, R.J., Wignall, P. and Sun, Y.D., 2011. Revised conodont zonation and conodont evolution across the Permian–Triassic boundary at the Shangsi section, Guangyuan, Sichuan, South China. *Global and Planetary Change*, v. 77, p. 103–115. <https://doi.org/10/cj3r9x>
- Jin, Y.G., Wang, Y., Henderson, C., Wardlaw, B.R., Shen, S.Z. and Cao, C.Q., 2006. The Global Boundary Stratotype Section and Point (GSSP) for the base of Changhsingian Stage (Upper Permian). *Episodes*, v. 29, p. 175–182. <https://doi.org/10/ghtnc2>
- Joachimski, M.M., Lai, X.L., Shen, S.Z., Jiang, H.S., Luo, G.M., Chen, B., Chen, J. and Sun, Y.D., 2012. Climate warming in the latest Permian and the Permian-Triassic mass extinction. *Geology*, v. 40, p. 195–198. <https://doi.org/10/fzc2pp>
- Lai, X.L., Jiang, H.S. and Wignall, P.B., 2018. A review of the Late Permian – Early Triassic conodont record and its significance for the end-Permian mass extinction. *Revue de Micropaleontologie*, v. 61, p. 155–164. <https://doi.org/10/ghtm3v>
- Lai, X.L., Yang, F.Q., Hallam, A. and Wignall, P.B., 1996. The Shangsi section, candidate of the Global Stratotype Section and Point of the Permian-Triassic Boundary, In Yin, H.F. (ed.), *The Paleozoic-Mesozoic Boundary Candidates of Global Stratotype Section and Point of the Permian-Triassic Boundary*. China University of Geosciences Press, Wuhan, p 113–124.
- Li, H.M. and Wang, J.D., 1989. Magnetostratigraphy of Permo-Triassic boundary section of Meishan of Changxing, Zhejiang. *Science China B-Chemistry*, v. 32, p. 1401–1408.
- Li, M.S., Hinnov, L. and Kump, L., 2019. Acycle: Time-series analysis software for paleoclimate research and education. *Computers & Geosciences*, v. 127, p. 12–22. <https://doi.org/10/ghtmxs>
- Li, Z.S., Zhan, L.P., Dai, J.Y., Jin, R.G., Zhu, X.F., Zhang, J.H., Huang, H.Q., Xu, D.Y., Yan, Z. and Li, H.M., 1989. Study on the Permian-Triassic biostratigraphy and event stratigraphy of northern Sichuan and southern Shaanxi. Geological Publishing House, Beijing.
- Liu, X.C., Wang, W., Shen, S.Z., Gorgij, M.N., Ye, F.C., Zhang, Y.C., Furuyama, S., Kano, A. and Chen, X.Z., 2013. Late Guadalupian to Lopingian (Permian) carbon and strontium isotopic chemostratigraphy in the Abadeh section, central Iran. *Gondwana Research*, v. 24, p. 222–232. <https://doi.org/10/f4zsdr>
- Liu, Y.Y., Zhu, Y.M. and Tian, W.H., 1999. New magnetostratigraphic results from Meishan section, Changxing County, Zhejiang Province. *Earth Science- Journal of China University of Geosciences*, v. 24, p. 151–154.
- Meng, X.H., Hu, C.S., Wang, W.M. and Liu, H.Y., 2000. Magnetostratigraphic study of Meishan Permian-Triassic section, Changxing, Zhejiang Province. China, *Journal of Earth Science*, v. 11, p. 361–365.
- Perri, M.C. and Farabegoli, E., 2003. Conodonts across the Permian–Triassic boundary in the Southern Alps. *Cour. Forschungsinstitut Senckenberg*, v. 245, p. 281–313.
- Richoz, S., Krystyn, L., Baud, A., Brandner, R., Horacek, M. and Mohtat-Aghai, P., 2010. Permian–Triassic boundary interval in the Middle East (Iran and N. Oman): Progressive environmental change from detailed carbonate carbon isotope marine curve and sedimentary evolution. *Journal of Asian Earth Sciences*, v. 39, p. 236–253. <https://doi.org/10/c5c85t>

- Scholger, R., 2000. Permian–Triassic boundary magnetostratigraphy from the Southern Alps (Italy). *Earth and Planetary Science Letters*, v. 176, p. 495–508. <https://doi.org/10/cv567j>
- Scholze, F., Wang, X., Kirscher, U., Kraft, J., Schneider, J.W., Götz, A.E., Joachimski, M.M. and Bachtadse, V., 2017. A multistratigraphic approach to pinpoint the Permian-Triassic boundary in continental deposits: The Zechstein-Lower Buntsandstein transition in Germany. *Global and Planetary Change*, v. 152, p. 129–151. <https://doi.org/10.1016/j.gloplacha.2017.03.004>
- Shen, J.H., Zhang, Y.G., Yang, H., Xie, S.C. and Pearson, A., 2022. Early and late phases of the Permian–Triassic mass extinction marked by different atmospheric CO₂ regimes. *Nature geoscience*, v. 15, p. 839–844. <https://doi.org/10.1038/s41561-022-01034-w>
- Shen, S.Z. and Mei, S.L., 2010. Lopingian (Late Permian) high-resolution conodont biostratigraphy in Iran with comparison to South China zonation. *Geological Journal*, v. 45, p. 135–161. <https://doi.org/10/bmfhqz>
- Shen, S.Z., Cao, C.Q., Zhang, H., Bowring, S.A., Henderson, C.M., Payne, J.L., Davydov, V.I., Chen, B., Yuan, D.X., Zhang, Y.C., Wang, W. and Zheng, Q.F., 2013. High-resolution $\delta^{13}\text{C}_{\text{carb}}$ chemostratigraphy from latest Guadalupian through earliest Triassic in South China and Iran. *Earth and Planetary Science Letters*, v. 375, p. 156–165. <https://doi.org/10.1016/j.epsl.2013.05.020>
- Song, H.J., Wignall, P.B., Tong, J.N. and Yin, H.F., 2013. Two pulses of extinction during the Permian–Triassic crisis. *Nature geoscience*, v. 6, p. 52–56. <https://doi.org/10/gg2w24>
- Steiner, M.B., Ogg, J.G., Zhang, Z. and Sun, S., 1989. The Late Permian/Early Triassic magnetic polarity time scale and plate motions of south China. *Journal of Geophysical Research: Solid Earth*, v. 94, p. 7343–7363. <https://doi.org/10.1029/jb094ib06p07343>
- Szurlies, M., 2013. Late Permian (Zechstein) magnetostratigraphy in Western and Central European. Geological Society, London, Special Publications, v. 376, p. 73–85. <https://doi.org/10/ghtnbv>
- Waterhouse, J.B., 2010. Lopingian (Late Permian) stratigraphy of the Salt Range, Pakistan and Himalayan region. *Geological Journal*, v. 45, p. 264–284. <https://doi.org/10.1002/gj.1235>
- Wei, H.Y., Zhang, X. and Qiu, Z., 2020. Millennial-scale ocean redox and $\delta^{13}\text{C}$ changes across the Permian–Triassic transition at Meishan and implications for the biocrisis. *International Journal of Earth Sciences*, v. 109, p. 1753–1766. <https://doi.org/10.1007/s00531-020-01869-x>
- Wu, B.J., Luo, G.M., Joachimski, M.M., Wignall, P.B., Lei, L.D., Huang, J.Y. and Lai, X.L., 2022. Carbon and nitrogen isotope evidence for widespread presence of anoxic intermediate waters before and during the Permian-Triassic mass extinction. *GSA Bulletin*, v. 134, p. 1397–1413. <https://doi.org/10/gr2spx>
- Wu, H.C., Zhang, S.H., Hinnov, L.A., Jiang, G.Q., Feng, Q.L., Li, H.Y. and Yang, T.S., 2013. Time-calibrated Milankovitch cycles for the late Permian. *Nature Communications*, v. 4, p. 2452. <https://doi.org/10.1038/ncomms3452>
- Wu, Y.Y., Tong, J.N., Algeo, T.J., Chu, D.L., Cui, Y., Song, H.J., Shu, W.C. and Du, Y., 2020. Organic carbon isotopes in terrestrial Permian-Triassic boundary sections of North China: Implications for global carbon cycle perturbations. *GSA Bulletin*, v. 132, p. 1106–1118. <https://doi.org/10.1130/B35228.1>
- Xie, S.C., Pancost, R.D., Huang, J.H., Wignall, P.B., Yu, J.X., Tang, X.Y., Chen, L., Huang, X.Y. and Lai, X.L., 2007. Changes in the global carbon cycle occurred as two episodes during the Permian–Triassic crisis. *Geology*, v. 35, p. 1083. <https://doi.org/10/b8fn2n>
- Yin, H.F., Zhang, K.X., Yang, Z.Y. and Wu, S.B., 2001. The Global Stratotype Section and Point (GSSP) of the Permian–Triassic Boundary. *Episodes*, v. 24, p. 102–114. <https://doi.org/10.18814/epiugs/2001/v24i2/004>
- Yin, H.F., Xie, S.C., Luo, G.M., Algeo, T.J. and Zhang, K.X., 2012. Two episodes of environmental change at the Permian–Triassic boundary of the GSSP section Meishan. *Earth-Science Reviews*, v. 115, p. 163–172. <https://doi.org/10/gg2tgt>
- Yuan, D.X., Chen, J., Zhang, Y.C., Zheng, Q.F. and Shen, S.Z., 2015. Changhsingian conodont succession and the end-Permian mass extinction event at the Daijiagou section in Chongqing, Southwest China. *Journal of Asian Earth Sciences*, v. 105, p. 234–251. <https://doi.org/10.1016/j.jseaes.2015.04.002>
- Yuan, D.X., Shen, S.C., Henderson, C.M., Chen, J., Zhang, H., Zheng, Q.F. and Wu, H.C., 2019. Integrative timescale for the Lopingian (Late Permian): A review and update from Shangsi, South China. *Earth-Science Reviews*, v. 188, p. 190–209. <https://doi.org/10/ghtmvx>
- Zhang, M., Qin, H.F., He, K., Hou, Y.F., Zheng, Q.F., Deng, C.L., He, Y., Shen, S.Z., Zhu, R.X. and Pan, Y.X., 2021. Magnetostratigraphy across the end-Permian mass extinction event from the Meishan sections, southeastern China. *Geology*, v. 49, p. 1289–1294. <https://doi.org/10.1130/G49072.1>
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- Publication summary: Insect biostratigraphy of the Late Pennsylvanian and Early Permian with reference to mixed Pennsylvanian-Permian floras**
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- Graphic abstract**
 Belahmira, A., Schneider, J.W. & Saber, H. (2024): Insect (Blattodea, Spiloblattinidae) biostratigraphy of the Pennsylvanian Souss basin, Morocco: a contribution to non-marine – marine correlation. – *Newsletters on Stratigraphy*, DOI: [10.1127/nos/2024/0821](https://doi.org/10.1127/nos/2024/0821)
- Abstract**
 Based on numerous new finds of blattoid insect wings in

the Upper Pennsylvanian strata of the Souss basin, High Atlas Mountains, Morocco (Fig. 1), detailed descriptions of several genera and species of the family Spiloblattinidae are provided. Emended diagnoses are given for this family as well as for the genera *Sysciophlebia* and *Spiloblattina*. Likewise, the diagnoses for the species *Sysciophlebia grata* and *Spiloblattina pygmaea* are specified and emended. Based on radioisotopic ages and, in places, on co-occurrences with conodonts in mixed continental-marine sections, the range of both these species as well as of *Sysciophlebia rubida* is discussed in relation to the Standard Global Chronostratigraphic Scale. Accordingly, the insect biostratigraphy of the Upper Carboniferous and Lower Permian is modified and significantly improved (Fig. 2). In conclusion, an age from late Kasimovian to early Gzhelian or late Stephanian A to Stephanian B, respectively, is assumed for the Oued Issene

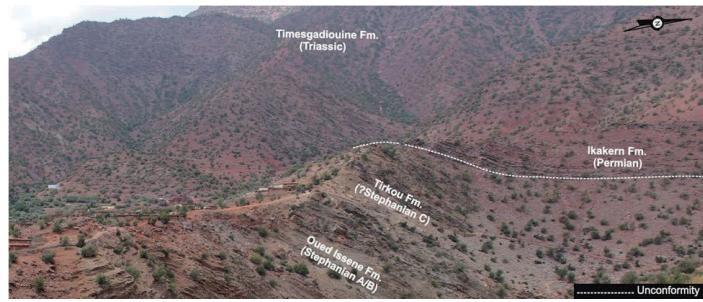


Fig. 1. Outcrop situation at Tanamert village in the Oued Issene canyon in the Ida Ou Ziki subbasin. Shown is the inclined uppermost part of the Stephanian A/B (Kasimovian/Gzhelian) Oued Issene Formation (Is) conformable but erosively overlain by the conglomerates of the Tirkou Formation of assumed Stephanian age. It follows red beds of the Middle to Upper Permian Ikakern Formation (T2) and the basal conglomerate, the Aid Driss Member, of the Triassic Timezgadiouine Formation (T3); both with an angular erosive unconformity at the base.

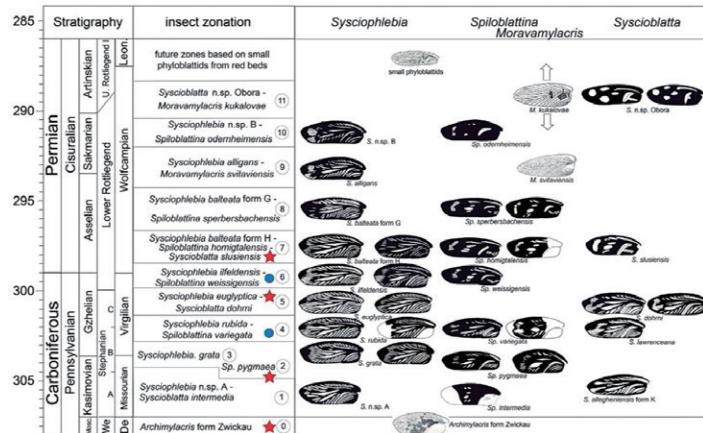


Fig. 2. Revised spiloblattinid zonation of Schneider et al. (2020, 2021b) based on the revised and described spiloblattinid genera and species. Compared to Schneider et al. (2021b) the zone species *Sysciophlebia grata* and *Sysciophlebia rubida* are reintroduced based on the new data. *Syscioblatta intermedia* is considered here as a basal species in the *Spiloblattina* lineage. The images show mostly idealized reconstructions of complete wings. The species rows of the spiloblattinids show the female forewings on the left and the male forewings on the right. Size of wings not to the scale. As a lower calibration point the radioisotopically dated *Archimylacris* form Zwickau is added (from Schneider et al. 2021b). As accompanying zone species two common forms of *Moravamylacris* are used in levels in which spiloblattinids are rare. Red stars mark the position of radioisotopic ages and blue dots the position of marine index fossils that are used for the calibration of the zones with the SGCS. For the data see the discussions in the text.

and El Menizla formations of the Souss basin. The macroflora associated with the entomofauna of these formations represent a mixture of typical Stephanian wetland floral elements and so-called mesophilous to xerophilous “Lower Permian” elements. Based on biostratigraphic dating, it represents one of the oldest evidences of the immigration of upper Palaeozoic extrabasinal floras into the basins of the Euramerican palaeotropical belt.

This publication aims to contribute to the tasks of the ‘Late Pennsylvanian – Permian – Early Triassic Non-Marine – Marine Correlation Working Group’ of the International Subcommissions on Carboniferous, Permian, and Triassic stratigraphy.

A report from the 9th International Brachiopod Congress “Brachiopods: Sentinels of the Phanerozoic”

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The 9th International Brachiopod Congress (IBC/CIB – 2024) “Brachiopods: Sentinels of the Phanerozoic” was held in Niagara Falls - St. Catharines, Ontario, Canada from June 24-27, 2024, with General Chair Uwe Brand, Department of Earth Sciences, Brock University, St. Catharines, Canada.

On the Main Campus of Brock University in St. Catharines, 46 delegates from all over the world (Canada, China, Denmark, Estonia, France, Germany, Hungary, Italy, Japan, Poland, Sweden, UK, USA) had the privilege to attend on the first day two very interesting workshops, one on “Microstructure and textural analysis of biological and geological materials” presented by Erika Griesshaber, and one “A Call to Action: Chemical Evolution of Paleozoic seawater: an update” presented by Uwe Brand.

On the other three days, the delegates attended three plenary talks and 34 oral presentations, which were long with plenty of time for discussion. The talks were supplemented by inspiring poster presentations ranging in scope from modern brachiopods to counterparts from as far back as the Cambrian.

The plenary talks were scheduled one per day as follows:

Wolfgang W. Schmahl, Brachiopod shells – What they teach us about biologic control of mineral growth and morphology the interplay of ontogeny and phylogeny

Lars E. Holmer, Phylogeny of Cambrian Brachiopods

Sandra J. Carlson, Brachiopod Evolution: The Interplay of ontogeny and phylogeny

Since brachiopods dominate many Paleozoic benthic communities, numerous talks were about Paleozoic brachiopods and several on Carboniferous and Permian brachiopods.

The congress was followed by a fantastic field trip to Friday Harbor, San Juan Island, Washington, U.S.A. (June 29-July 2,

2024) to sample living brachiopods as well as other benthic invertebrates. This was an unparalleled experience that allowed us to sample in-situ biotic archives and eventually test their fidelity as tools for paleoclimatic and paleoenvironmental reconstructions in the geological past. This is particularly important for Permian studies, as brachiopods are one of the best and most abundant archive of proxies in this time interval. We still have so much to learn from the Present to understand the geologic Past.

Update: The 10th International Brachiopod Congress will be held in Cambridge, UK in three-years time.



Group photo of the 9th International Brachiopod Congress "Brachiopods: Sentinels of the Phanerozoic". The Chair Uwe Brand in the foreground.



Sampling living brachiopods (and not only...) during the field trip at Friday Harbor.

In commemoration of Prof. Emeritus Giuseppe Cassinis

Cesare Perotti, Ausonio Ronchi

Dipartimento di Scienze della Terra e dell'Ambiente Università di Pavia-Via Ferrata, Italy

Professor Emeritus Giuseppe Cassinis passed away on November 14, 2023, and his death was a painful loss for all his friends and colleagues in the Department of Earth and Environmental Sciences at the University of Pavia. With him disappears not only a great and valiant scientist, but also a man rich in humanity and sympathy who was an example of seriousness and correctness for all of us.

Giuseppe Cassinis, Bepi to his friends, was born on 4 August 1934 in Cagliari. He obtained a degree in Geological Sciences in 1956 at the Università Statale of Milan. His experimental thesis was titled: "The geology of the Collebeato - Caino - Valgobbia area, north of Brescia", and was awarded first prize in the 10th competition organized by the Ugo da Como Foundation of Lonato. From 1 December 1956 he became assistant in charge of Geology at the University of Milan and in 1958 he became full assistant in the same role.

On 1 October 1962 Cassinis became Researcher of the National Research Council (C.N.R.), in the Institute of Geology at the University of Pavia, until he became Chief Researcher in 1968. In 1971 he obtained the "Libera Docenza" in Stratigraphic Geology.

Cassinis was later appointed Full Professor of Geology for the degree course in Natural Sciences at the Faculty of Sciences MM.FF.NN. at the University of Pavia on 1 November 1980. He taught "Stratigraphic Geology" for the degree course in Geological Sciences from 1984 until his retirement in November 2009.

In 2010 he was appointed Professor Emeritus at the University of Pavia.

During his long and fruitful career, he held numerous institutional roles, of which we mention only the most significant:

- corresponding member of the Ateneo di Brescia (1971)
- corresponding member from 1986 to 1989, full member from 1989 to 2005 and honorary member from 2005 of the "Sub-commission on Permian Stratigraphy" (SPS), belonging to the International Stratigraphic Commission (ICS)
- corresponding member since 1991 and effective member since 1996 of the Istituto Lombardo-Accademia di Scienze e Lettere, of which he was secretary from 1997 to 2004
- councilor of the Board of Directors of the Italian Geological Society from 1983 to 1985 and member of the scientific committee organizing the events of the I Centenary (1881-1981) of the Italian Geological Society;
- member of the Editorial Committee of the periodicals of the Italian Geological Society for the years 1981 and 1982;
- Pavia representative of the PhD in Earth Sciences, in a consortium association of the Universities of Ferrara, Florence, Parma, Perugia and Siena, with administrative headquarters in Florence and then in Parma, from 1986 to 1994;

- president of the AGPT (Association of Permian and Triassic Geologists) from 2007 to 2009. It has its official headquarters in Paris and he had been a member since its foundation (1987). Until his death he held the position of vice president and member of the Board of Directors;

- national manager of the geological scientific cooperation between the National Research Council and the Bulgarian Academy of Sciences, from 1995 to 2000. Receiving a certificate of merit for the activity carried out in the aforementioned period;

- national coordinator of various IGCP projects since 1979. Including n. 106 and 203 ("Permian-Triassic events in the Eastern Tethys Region and their intercontinental correlation"), n. 272 ("Late Palaeozoic and Early Mesozoic circum-Pacific events and their global correlation"), n. 343 ("Stratigraphic analysis of peri-Tethyan basins"), n. 359 ("Correlation of Tethyan, circum-Pacific and marginal Gondwanan Permo-Triassic") and n. 369 ("Comparative evolution of peri-Tethyan rift basins");

- organizer of the international congresses in Brescia (1986 and 1999) and Siena (2001 and 2006), having as their theme the Permian and the late European and non-European Paleozoic-Lower Mesozoic. All conferences were accompanied by excursions to Sardinia, the central-eastern South Alpine region, Tuscany and southern France;

- national scientific coordinator of several PRIN research projects.

Cassinis' intense and continuous scientific research activity is documented by over 250 scientific articles, most of which were published in international peer-reviewed journals. There are also more than 50 communications presented at both national and international conferences, plenary lectures and invited conferences at Italian and foreign universities. He was also Editor or co-Editor of numerous scientific volumes including:

- "Permian and Permian-Triassic boundary in the South-Alpine segment of the Western Tethys, and additional regional reports",

- "Late Palaeozoic Continental Basins of Sardinia",
• "The continental Permian of the Southern Alps and Sardinia (Italy). Regional reports and general correlations",

- "Late Palaeozoic to Early Mesozoic events of Mediterranean Europe, and additional regional reports",

- "Non-Marine Permian Biostratigraphy and Biochronology".

Cassinis carried out an impressive number of geological cartographic activities, collaborating on the preparation and in many cases assuming the scientific responsibility of numerous geological maps, many of which related to the official Geological Cartography of Italy.

His most significant scientific contributions concerned the following topics:

- The stratigraphy and sedimentology of the Triassic and Jurassic deposits of Eastern Lombardy and Southwestern Trentino, with particular attention to the Brescia Pre-Alps. In this regard, a series of scientific contributions on the Jurassic sediments (the "Medolo" and "Concesio" units) in the area between Brescia and Val Trompia and on the palaeoenvironmental, palaeogeographic and structural characteristics of the Val Trompia Jurassic basin are of fundamental importance.



Autun AGPT 2007: with Renée and Bernard Damotte.



Cordigliera Iberica AGPT 2004: with Marceliano Lago (left), José-Bienvenido Diez (right, shoulders), Jean-Jacques Chateauneuf (left, shoulders) and unnamed person.

- The stratigraphic and sedimentological characteristics of the Permian deposits of the Southern Alps. In fact, Giuseppe Cassinis was the author of the first modern studies of the Permian Collio Basin, presenting a detailed definition of its stratigraphic succession, morphology and paleo-environmental and geodynamic significance. The stratigraphic subdivisions adopted



Marine-non Marine Congress, Albuquerque 2005: from the left Jean Broutin, Marc Durand, Jean-Sébastien Steyer and Ausonio Ronchi.

are still fully valid and the dating carried out on a paleontological basis has also recently received substantial confirmation.

- The stratigraphy, paleogeography and geodynamics of the late- and post-Hercynian basins in the Southern Alps, Tuscany and Sardinia and comparisons with other areas of the western Mediterranean and Europe. In particular, identification in the Alpine area of two main tectono-sedimentary cycles, separated by an infra-Permian gap of several million years and by a marked angular unconformity, represents a discovery of primary importance for defining the paleogeographic and geodynamic change of Europe after the Hercynian orogeny. Comparisons with other European areas have in fact made it possible to find significant similarities and differences and to frame the Permian and Triassic events in a substantially unitary and well-defined paleo-environmental framework.

- The late Paleozoic and Triassic magmatic activity of the Brescian Alps and its possible geodynamic significance. This research, conducted in collaboration with scientists from the University of Genoa, has provided a substantial amount of geological and petrographic data on the products of Permian and Triassic magmatism in eastern Lombardy.

Giuseppe Cassinis can surely be considered one of the world's leading experts on European and non-European Permian continental deposits. His studies have made a substantial contribution toward understanding the environmental, paleogeographic and geodynamic evolution of Europe from the end of the Variscan orogeny to the beginning of the Mesozoic.

The scientific contribution and international fame of Giuseppe Cassinis were fundamental for the growth and development of the Pavia School of Geology, stratigraphy and regional geology. His continuous and fruitful scientific activity closely connected to equally intense teaching activity has played a role of primary importance in the training and growth of generations of geologists graduated from our university, who found in him a constant scientific point of reference, for both professional and ethical understanding.

Beyond his impressive titles and academic merits, Bepi

Cassinis was truly a constant point of reference for all his colleagues, not only from a scientific point of view, but above all from a human point of view.

His extraordinary personal empathy, his sympathy, his rare ability to share problems and difficulties and his availability are a model for all of us to follow. With him disappeared a scientist who contributed to consolidating prestige in the world of Italian geology and a good, generous and altruistic man.

In life it is difficult to meet true friends, especially in the workplace; for this reason we will always remember Bepi and the friendship that he expressed to us and this memory will be a source of comfort and consolation for us.

Daniel Vachard (1947-2024): In memoriam

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Spencer G. Lucas

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Daniel Vachard was born on May 6, 1947 in Nanterre, Hauts de Seine, in the western suburbs of Paris. He died on June 23, 2024, just a few weeks before we submitted for publication a manuscript on Mississippian foraminifers from the Sierra Nacimiento in New Mexico. After completing secondary school and university studies, in 1980 he finished his doctoral thesis with distinction at the Institut Géologique Albert-de-Lapparent (IGAL) titled "Tethys and Gondwana in the late Paleozoic: data from Afghanistan."

Vachard spent his career as a professor at the Université des Sciences et Technologies de Lille UFR, Sciences de la Terre, Villeneuve d'Ascq (France). After his retirement 2012 he continued his scientific work at his home in Gruson near Lille as a member of the self proclaimed "Collegial and International Research Centre of Active Seniors (CIRCAS)."

Daniel Vachard was one of the premier experts on the micropalaeontology of smaller foraminifers, fusulinids, and calcareous algae, and their evolution, biostratigraphy, palaeoecology and palaeobiogeography. He made substantial contributions to Middle Devonian to Triassic biostratigraphy, and especially to Carboniferous and Permian biostratigraphy, in France, Belgium, Spain, Morocco, Libya, Tunisia, Oman, Saudi Arabia, Greece, Austria, Turkey, Iran, Afghanistan, Thailand, Malaysia, Indonesia, South China, Australia, Mexico, New Mexico (USA) and Guatemala. A good example of his important work on Permian biostratigraphy is his 2018 article titled "Permian smaller foraminifers: taxonomy, biostratigraphy and biogeography," published by the Geological Society of London in its Special Publication 450. This masterful review of the Permian record of non-fusulinid foraminifers attested to Vachard's broad and deep knowledge of the subject.



Daniel Vachard with his wife Therése (deceased 14 November 2023) in July 2012 near Calais, France.

Indeed, Vachard's contributions to our understanding of Permian microfossils were diverse. They include documentation and revision of the Lower Permian foraminifers (including fusulinids) and microproblematica from the Carnic Alps (Austria/Italy), published in 2019 in volume 73 of the *Abhandlungen der Geologischen Bundesanstalt* (Geological Survey of Austria). A detailed study on Lower Permian cyanobacteria and calcareous algae from the Carnic Alps was published in *Palaeontologia Electronica* in 2019. He also published an extensive study of Lower Permian microfossils from southern New Mexico in *Palaeontologia Electronica* in 2015. A comprehensive study on calcareous algae and foraminifers across the Permian-Triassic boundary in the Dolomites (Italy) was published in 2022 in volume 324 of *Palaeontographica, Abteilung A: Palaeozoology-Stratigraphy*.

One of us (KK) first met Daniel Vachard in 1999 in Lille, and since then Krainer and Vachard undertook an extensive collaboration on foraminifers and calcareous algae, starting in the upper Paleozoic succession of the Carnic Alps (Austria/Italy) and moving to the upper Paleozoic of New Mexico, when collaboration with Lucas began. KK worked Vachard several times in Lille and Gruson, and in Innsbruck, to study thin sections of foraminifers and calcareous algae. The collaboration resulted in numerous publications that advanced our understanding of Carboniferous and Permian correlations and paleoenvironments.

Daniel Vachard was an important micropaleontologist who contributed an enormous amount of important data and analysis to the paleobiology, biostratigraphy and paleogeography of foraminifers and other calcareous microfossils of the late Paleozoic and Triassic. His scientific work resulted in over 500 publications. With his death, we lost not only a great paleontologist, but also a good friend.



Mafra, SC, Brazil | December 7-10, 2025



6th International Conodont Symposium - ICOS 6

The Organizing Committee invites you to the 6th International Conodont Symposium - ICOS 6, which will be held in Mafra City, Santa Catarina State, South Brazil, during early December 2025. The scientific program will cover all aspects of conodonts, and the symposium will provide researchers an opportunity to present their experiences, projects and results. The symposium will include two full days of scientific sessions, a one-day visit to the Lagerstätte fossil-shale Campaleo outcrop, with conodont natural feeding apparatus and, a post-symposium field trip to one of Gondwana's most magnificent exhibits.

The four-day post-symposium field trip is of particular significance to Permian workers. It will start from beautiful beaches with clean and warm waters and head up to the mountains along the Serra do Rio do Rastro Highway. There will be a visit to a classic geological section of the Gondwana Supercontinent in the Paraná Basin, Brazil (White Column). This stratigraphical section was erected in 1908 consisting of a geological succession of the outcropping units of the Paraná Basin in the SC-438 Road. It includes the glacial unit named the Itararé Group, of Pennsylvanian/Permian age, to the magmatic extrusions of the Serra Geral Formation, of Cretaceous age.

Professor Ana Karina Scomazzon, UFRGS, Rio Grande do Sul State - RS, Brazil

GeoTolosa2025 – News from the Palaeozoic World will be held June 24th-27th 2025, at the University Toulouse III Paul Sabatier (Toulouse, France).

GeoTolosa2025 will bring together scientists from around the globe who study the geosphere, biosphere and atmosphere of Devonian, Carboniferous and **Permian** times, scientific communities who usually gather separately at the International Congress on the Carboniferous and Permian (ICCP), VARISCAN or International Subcommission on Devonian Stratigraphy meetings.

GeoTolosa2025 will cover a wide range of topics and disciplines related to the endogenic and exogenic processes such as stratigraphy and palaeontology, sedimentology and basin evolution, paleoclimate and palaeoceanography, tectonics, geodynamics and palaeogeography, and orogenic systems (e.g., Variscan, Central Asian Orogenic Belt).

All communities will have the possibility to organize specialized sessions during the indoor meeting over 4 days. The program will be associated with pre- and post-meeting field trips illustrating the Devonian to Permian of France.

In Early September the first circular will be distributed including a call for sessions, the conference web site will go online, and social media activities will start.

SUBMISSION GUIDELINES FOR ISSUE 78

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.

Prof. Yichun Zhang (SPS secretary)

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The deadline for submission to Issue 78 is December, 31, 2024

Age (Ma)	Series/stage	Magnetic polarity units	Conodonts		Fusulines	Radiolarians
250	Triassic		<i>Isarcicella isarcica</i> <i>Hindeodus parvus</i>			
252	251.902±0.024	LP3	I2 I1	L11-L13 <i>Clarkina changxingensis</i> <i>Clarkina subcarinata</i> <i>Clarkina wangii</i>	<i>Palaeofusulina sinensis</i>	Unzoned <i>Albaillella yaoi</i> <i>Albaillella optima</i> <i>Albaillella triangularis</i> <i>Neoalbaillella ornithoformis</i>
254	Changhsingian	LP2	L10 L9 L8	<i>Clarkina orientalis</i> <i>Clarkina transcaucasica</i> <i>Clarkina guangyuanensis</i>	<i>Palaeofusulina minima</i>	
256	254.14±0.07	LP2n	LP1r LP1n LP0r	<i>Clarkina longicuspidata</i> <i>Clarkina liangshansiensis</i> <i>Clarkina leveni</i> <i>Clarkina asymmetrica</i> <i>Clarkina dukouensis</i> <i>Clarkina postbitteri</i>	<i>Gallowayinella meitiensis</i>	<i>Albaillella excelsa</i> <i>Albaillella levius</i>
258	Wuchiapingian	LP1	L7 L6 L5 L4 L3 L2		<i>Nanlingella simplex</i> - <i>Codonofusula kwangsiana</i>	<i>Albaillella cavitata</i>
260	259.51±0.21	GU3n	L1 G7 G6 G5 G4 G3	<i>Jinogondolella granti</i> <i>Jinogondolella xuanhanensis</i> <i>Jinogondolella prexuanhanensis</i> <i>Jinogondolella altadensis</i> <i>Jinogondolella shannoni</i> <i>Jinogondolella postserratia</i>	<i>Lantschichites minima</i> <i>Metadololina multivoluta</i>	<i>Follicucillus charveti</i>
262	Capitanian	Gu2n.1n	G2		<i>Yabeina gubleri</i>	<i>Follicucillus scholasticus</i>
264	264.28±0.16	GU1r GU1n		<i>Jinogondolella aserrata</i>	<i>Afghanella schencki</i> / <i>Neoschwagerina margaritae</i>	<i>Follicucillus porrectus</i>
266	Wordian	GU1n			<i>Neoschwagerina craticulifera</i>	<i>Follicucillus monacanthus</i>
268	266.9±0.4					
270	Roadian	Kuhfengian	Cl3r.1n	<i>Jinogondolella nankingensis</i>		<i>Pseudoalbaillella globosa</i>
272	273.01±0.14	Xiangboan	C15	<i>Mesogondolella lamberti</i>	<i>Neoschwagerina simplex</i>	<i>Pseudoalbaillella ishigai</i>
274			Cl3n	<i>Sweetognathus subsymmetricus</i> / <i>Mesogondolella siciliensis</i>	<i>Cancellina liuzhiensis</i>	
276	Kungurian		C14	<i>Sweetognathus guizhouensis</i>	<i>Maklaya elliptica</i>	<i>Albaillella sinuata</i>
278			C13		<i>Shengella simplex</i>	
280					<i>Misellina claudiae</i>	
282			C12	<i>Neostreptognathodus pnevi</i>	<i>Misellina termieri</i>	<i>Albaillella xiaodongensis</i>
284	Artinskian	Longnian	C11	<i>Neostreptognathodus exsculptus</i> / <i>N. pequopensis</i>	<i>Misellina (Brevaxina) dyrehfurthi</i>	
286	283.5±0.6	Kiaman Reversed Superchron	Cl2n			<i>Pseudoalbaillella rhombohoracata</i>
288			C10	<i>Sweetognathus asymmetricus</i>	<i>Pamirina darvasica</i> / <i>Laxifusulina-Chalaroschwagerina inflata</i>	
290	Sakmarian	Zisongian	C9	<i>Mesogondolella bisselli</i> / <i>Sweetognathus anceps</i>	<i>Robustoschwagerina ziyunensis</i>	<i>Pseudoalbaillella lomentaria</i>
292	290.5±0.4		C8	<i>Mesogondolella manifesta</i>		<i>-Ps. sakmarenensis</i>
294			C7	<i>Mesogondolella monstra</i> / <i>Sweetognathus binodosus</i>		
296	Asselian		C6	<i>Sweetognathus aff. merrilli</i> / <i>Mesogondolella uralensis</i>	<i>Sphaeroschwagerina moelleri</i>	<i>Pseudoalbaillella u-forma</i>
298	293.52±0.17		C5	<i>Streptognathodus barskovi</i>	<i>Robustoschwagerina kahleri</i>	<i>-Ps. elegans</i>
300	298.9±0.15		C4	<i>Streptognathodus fusus</i>	<i>Pseudoschwagerina uddeni</i>	<i>Pseudoalbaillella bulbosa</i>
	Carboniferous		C3	<i>Streptognathodus constrictus</i>		
			C2	<i>Streptognathodus sigmoidalis</i>		
			C1	<i>Streptognathodus isolatus</i>		
			Cl1n	<i>Streptognathodus wabaunsensis</i>	<i>Triticites</i> spp.	

High-resolution integrative Permian stratigraphic framework (after Shen et al., 2019. Permian integrative stratigraphy and timescale of China. *Science China Earth Sciences* 62(1): 154–188. Guadalupian ages modified after (1) Shen et al., 2020. Progress, problems and prospects: An overview of the Guadalupian Series of South China and North America. *Earth-Science Reviews*, 211: 103412 and (2) Wu et al., 2020, High-precision U-Pb zircon age constraints on the Guadalupian in West Texas, USA. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 548: 109668. Lopingian ages modified after Yang et al., 2018, Early Wuchiapingian cooling linked to Emeishan basaltic weathering? *Earth and Planetary Science Letters*, 492: 102–111. Base-Artinskian age modified after Henderson and Shen, 2020. Chapter 24-The Permian Period. In Gradstein F.M., Ogg, J.G., Schmitz M.D., and Ogg, G.M. (eds.), *The Geologic Time Scale 2020*, Elsevier, v. 2, p. 875–902. The position of the beginning of the Illawarra Reversal is not indicated in the table because it is still controversial, having been placed in the earliest Wordian (Hounslow and Balabanov, 2018), in the middle Wordian (Jin et al., 1999; Steiner, 2006; Henderson et al., 2012; Lenci et al., 2013; Shen et al., 2013a, 2019b; Henderson and Shen, 2020), slightly below the base of the Capitanian (Shen et al. 2022) or in the earliest Capitanian (Menning, 2000; Isozaki, 2009). For references see Shen et al., 2020. Progress, problems and prospects: An overview of the Guadalupian Series of South China and North America. *Earth-Science Reviews*, 211: 103412; Shen et al., 2022. The Global Stratotype Section and Point (GSSP) for the base of the Capitanian Stage (Guadalupian, Middle Permian). *Episodes*, 45, 3: 309–331.