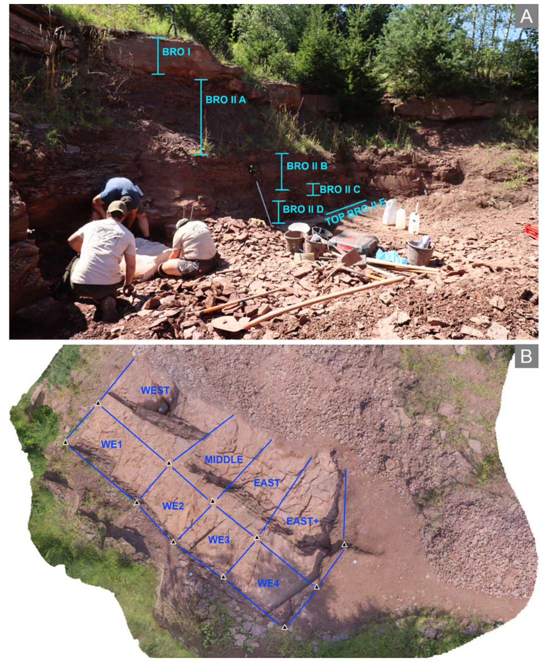
Permophiles

International Commission on Stratigraphy



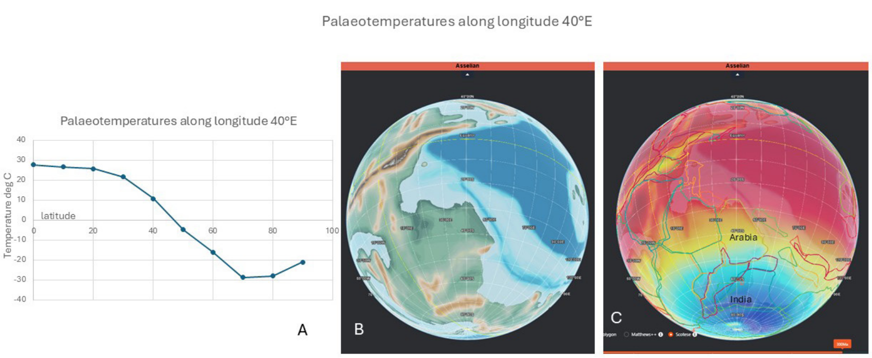
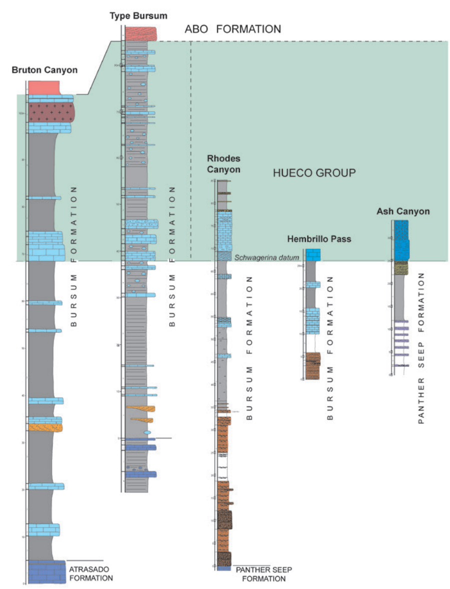
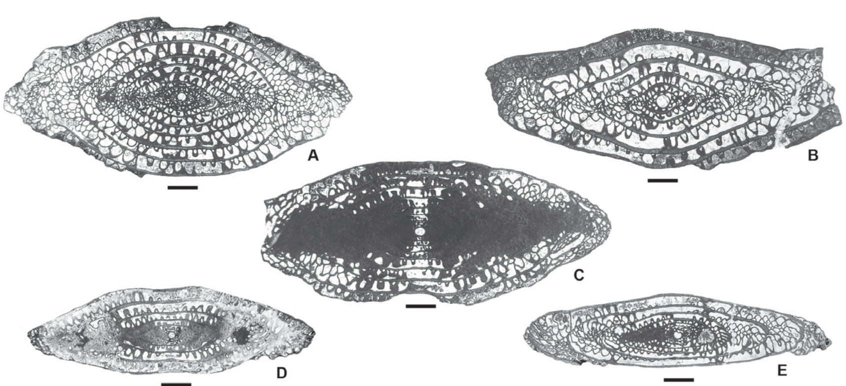


Fig. 1





Newsletter of the Subcommission on Permian Stratigraphy

Number 79

ISSN 1684-5927

September 2025

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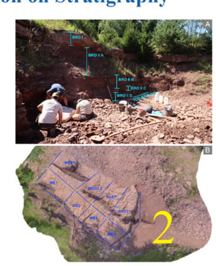
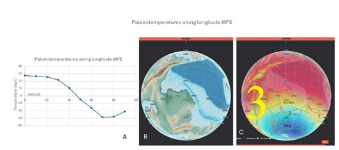
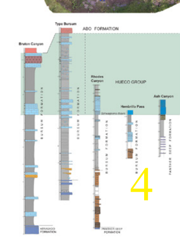
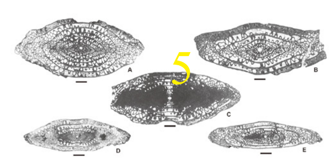

Fig. 1. Participants in GeoTolosa 2025 meeting (20th ICCP). From Left to right: Ladislav Slavik, Elizabeth (Liz) A. Weldon, Markus Aretz and Charles M. Henderson.

Fig. 2. Layer packages and excavated sectors. Lorenzo Marchetti et al, this issue.

Fig. 3. Palaeotemperature modelling for 40°E across the southern hemisphere from the equator to the south pole. Michael H. Stephenson, this issue.

Fig. 4. Correlation of stratigraphic sections of the Bursum Formation, Hueco Group and adjacent strata in the Orogrande basin of southern New Mexico. Spencer G. Lucus and Karl Krainer, this issue.

Fig. 5. Fusulinids from the Simpson Canyon 4045 Unit #1 well, Crockett County, TX. Michael T. Read, this issue.

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Notes from the SPS secretary
Yichun Zhang

Introduction and thanks

I started to edit this issue of *Permophiles* when I was having fieldwork in northern Tibet (Xizang of China) with an average altitude over than 5000 m. Even in summer time, we often encountered heavy snow and chill wind. Hopefully, I can stay in my office in Nanjing to finish the edition of this issue.

In 25th June, a SPS business meeting was held in Toulouse, France during the Geotolosa2025 conference. The meeting was chaired by Dr. Liz Weldon (SPS Chair). She introduced the rules of ICS and the future plan of SPS. Subsequently, Prof. Ausonio Ronchi, Prof. Charles Henderson and I reported the work of five working groups in SPS. As I always said, SPS is effective in establishing GSSPs and organizing working groups. Thanks all colleagues for their great work.

This issue of *Permophiles* contains interesting articles covering the Permian taxonomy, biostratigraphy and global correlations. Thanks to all contributors of this issue: Charles M. Henderson, Spencer G. Lucas and Karl Krainer, Michael H. Stephenson, Lorenzo Marchetti and co-authors, Michael T. Read, Iván R. Barreiro and co-authors, Pauline Sabina Kavali and co-authors, Lilit Sahakyan and Aymon Baud.

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As usual, this issue starts with Henderson's Harangue #15. He still highlights the values of GSSPs and suggests that attention should be paid on global correlations. This is also the goal of GSSP.

Spencer G. Lucas and Karl Krainer present a correlation of Bursum stratigraphic sections in southern New Mexico that correlating the upper Bursum to the lower Hueco Group on the WSMR and vicinity, which has important implications for regional lower Permian stratigraphy and chronostratigraphy.

Michael H. Stephenson evaluates the palaeotemperature and palaeoprecipitation modelling by testing the changes in palaeotemperature along two lines of longitude, 40°E and 140°E across the southern hemisphere from the equator to the south pole in the Asselian. The result is interesting and effective. The DDE is very powerful in future Permian studies.

Lorenzo Marchetti and co-authors introduce the detailed process of BROMACKER project in excavation of abundant fossils and sedimentary structures in the Bromacker locality, central Germany.

Michael T. Read studies the fusulinids and conodonts from the Simpson Canyon 4045 Unit # 1 wellsite. The biostratigraphy suggests the correlation of Wolfcamp B-Wolfcamp A transition with middle Artinskian.

Iván R. Barreiro and co-authors revise the pollen *Nuskoisporites*. Morphotypes 1 and 2 have been recognized with different temporal ranges.

Pauline Sabina Kavali and co-authors revaluate the Indian spores and pollens and suggest *Cannanoropollis* to incorporate some species in *Parasaccites*.

Lilit Sahakyan and Aymon Baud comment on the paper "Uppermost Permian to Lower Triassic conodont biostratigraphy and carbon isotope records from Southern Armenia" published on *Palaeogeography, Palaeoclimatology, Palaeoecology* by Han et al.

Future issues of Permophiles

The next issue of *Permophiles* will be the 80th 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 80 is 31 December 2025.

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
Elizabeth A. Weldon

Welcome to the 79th issue of *Permophiles*!

In June I attended GeoTolosa 2025 incorporating the 20th ICCP (International Congress on the Carboniferous and Permian) and the Variscan Meeting 2025. At the Congress we held an SPS Business Meeting, including reports presented from all five working groups. A dedicated session on 'Permian Biota and Stratigraphy' was included in the program, and the Permian community was well represented in sessions on geodynamics, the sedimentary record, and various aspects of palaeoenvironmental change. There was also a post-congress field trip to the Lodève-Graissessac Basin to see the Late Carboniferous and Permian geology and palaeontology. A special thanks to Markus Aretz, Domonique Chardon and the organising committee for hosting a successful event at the University of Toulouse, France.

At the SPS Business Meeting I formally thanked Ausonio Ronchi and Joerg Schneider for their 12 years of service to the Permian community as voting members on the SPS. Joerg has also served as Vice-Chair of SPS and has been a regular contributor to *Permophiles*. Joerg retains his current role as Chair of the Correlation between marine and continental Carboniferous-Permian Transition Working Group. Ausonio also continues to serve the SPS through membership of the Base-Roadian Working Group and Correlation between marine and continental Carboniferous-Permian Transition Working Group. We also look forward to their continued involvement in Permian research.

The SPS voting membership can include up to 20 members and should according to the Statutes *represent regional and methodological diversity in an appropriate manner*. With this in mind, the Executive would like to welcome into the SPS three new voting members Pauline Kavali, Gabriela Cisterna, and Evelyn Kustatcher. Dr. Pauline Kavali is a researcher at Birbal Sahni Institute of Palaeosciences in Lucknow, India. Pauline is a palynologist working on Late Palaeozoic and Mesozoic material from both India and South America to resolve gaps in global correlation and palaeobiogeography. Prof. Gabriela Cisterna is a researcher at CONICET and a Professor of Regional Geology at the Universidad Nacional de La Rioja, Argentina. Her research focuses on the systematics, biostratigraphy, and paleoecology of Carboniferous and Permian brachiopods from Gondwanan basins. Dr. Evelyn Kustatscher is head of department of Natural History of the Tyrolean State Museums in Innsbruck and teaches paleobotany at the LMU Munich, Germany. Her main research focuses on fossil plants and spores/pollen from the Palaeozoic and Mesozoic to understand how terrestrial ecosystems responded to supervolcanic eruptions, climate change, and mass extinction events. I am also pleased to welcome Dr. Iván R. Barreiro from the Museum of Nature South Tyrol, Italy, as our new Editor of *Permophiles*. Iván is a corresponding member of the SPS and part of Evelyn's team.

Both our new and existing voting members have some important work ahead of them in the coming months. One of the key responsibilities of the SPS is to *define the series and stages of the Permian by means of internationally agreed GSSPs*. Over many years the SPS has been very active in achieving this goal and the Kungurian is the only Permian stage that has not yet been ratified with a GSSP at its base. Our Base-Kungurian Working Group, led by Charles Henderson, is nearing the completion its work on the Rockland Section, Nevada, USA, and the members are preparing to present a proposal to the SPS very soon. For information on the protocols and ratification process of a new GSSP please refer to the International Commission on Stratigraphy GSSP link. After ratification the proposal is published, and a physical marker, a 'Golden Spike,' should be placed at the GSSP stratotype locality. Recently in the Republic of Bashkortostan on 11 June 2025, 'Golden Spikes' were officially launched in a public dedication ceremony at the Usolka and Dalny Tyulkas geological sections. The Usolka section acquired GSSP status for the base of the Sakmarian Stage in 2018 and Dalny Tyulkas section acquired GSSP status for the base of the Artinskian Stage in 2022.

And finally for this issue, I would like to thank everyone for the high-quality contributions coming into *Permophiles* and remind everyone to regularly check in on the SPS website. Recently we posted a recording of Prof. Junxuan Fan and teams' SPS webinar presentation on 'CONOP: Horizon Sequencing, and Graph-Optimized Graphic Correlation in Stratigraphy' and Prof. Yichun Zhang's 'Compilation of selected papers published on Permian topics.' You can find them here: Subcommission on Permian Stratigraphy. Also, don't forget to download the latest circular for Strati2026 at https://www.strati2026.org/. Strati2026 will be an ICS dedicated meeting, and we plan to hold an SPS in-person business meeting at the conference.

APPENDICES

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2) Base-Roadian Working Group
Leader: Prof. Charles Henderson
3) Base-Wordian Working Group
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4) Correlation Between Marine and Continental Carboniferous-Permian Transition Working Group
Leader: Prof. Joerg Schneider
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Henderson's Harangue #15

Charles M. Henderson
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All the world's a Stage: Is it?

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

In my past two harangues in *Permophiles* I suggested that the necessary extraordinary effort by many geoscientists to successfully ratify a Stage GSSP deserves a celebration. The Geologic Time Scale is one of the greatest inventions of our species because it temporally subdivides the entire history of our planet!

"All the world's a stage, and all the men and women merely players; they have their entrances and exits…" is the opening monologue from Shakespeare's comedy "As You Like It". I don't want to carry this analogy too far since I am far from a scholar of Shakespeare's great works. Truly I wish only a play on words since the stage of Shakespeare is very different from the stage of the Geologic Time Scale. But the process of defining stages has many players and they have had their entrances and exits. To name but a few, I have had the honour of working in the field with Brian Glenister, Bruce Wardlaw, and Jin Yugan. All very different with very distinct personalities, once pushy and profound, or loud and boisterous, and even thoughtful and quiet – each at different times, but always passionate about the Permian. All are gone from the stage, but their performances remain recorded in words and in our minds. My own time to exit the stage is perhaps closing in....but not yet! Having retired on February 1 of this year, I have – perhaps entered the fifth stage of my life as an active, wise (or substitute, as you like it) old man of the Permian.

The Permian has a long history since it was named by Sir Roderick Murchison in 1841, but the Permian I speak of is that envisioned by Jin et al. (1997). It has nine stages and all but one, the Kungurian, has been ratified. Stay tuned for the next issue of *Permophiles* (#80) for more on the Kungurian. This Permian time scale is a great compromise! The stages are set to the evolutionary beat of conodonts, but they don't define the stage boundaries, rather they serve as one of many tools to correlate the stages. GSSPs serve to define the lower boundary of stages leaving the remainder of the stage up to the next lower boundary seemingly empty, as suggested by some. Until a stage is defined, however, there is no way to fill that so-called empty void. All of this became particularly clear to me when I was preparing my abstract on the Sakmarian for the June meeting of Geotolosa in Toulouse.

The abstract is entitled "Near-global correlation of the Sakmarian Stage (Cisuralian, Lower Permian): A Case Study". The abstract is reproduced in my part of the SPS Members of the "Gondwana to Euramerica correlations working group" report in this issue of *Permophiles*. Conodonts are useful for correlating many Sakmarian successions but are absent in several locations in Argentina and the Verkhoyansk region of NE Russia, for example. The initial focus was directed at the Lyall River section on Grinnell Peninsula of Devon Island in the Canadian Arctic that I first visited in 1986. A current student, my last, is finishing her MSc thesis on upper Pennsylvanian to Lower Permian correlations from Grinnell Peninsula to Bjorne Peninsula on SW Ellesmere Island. To assist her, I needed to reconsider some of the correlations of two formations (Raanes and Great Bear Cape) that Benoit Beauchamp and I named (Beauchamp and Henderson, 1994). The conodonts and especially the fusulinids at the Lyall River section were important for correlation to the Jungle Creek and lower Tahkandit formations at the Tatonduk River Section in the Yukon Territory of Canada where brachiopods were especially well studied (Bamber and Waterhouse, 1971). Shi and Waterhouse (1996) restudied the brachiopods and identified some "bipolar" species including *Jakutoproductus verchoyanicus*. In turn, these bipolar brachiopods allowed correlation to sections in NE Russia that had been studied by Ruslan Kutygin (Kutygin et al., 2020) among others and to sections in Argentina studied by Arturo Toboada and Alejandra Pagani (2010) among others. Kutygin also pointed to the occurrence of the ammonoids including *Neoshumardites triceps* above the bipolar brachiopods that correlates with ammonoids near the Sakmarian-Artinkskian boundary on Bjorne Peninsula. In doing all this, a near global correlation had been achieved for the entire Sakmarian, despite some sections lacking conodonts and fusulinids. It turns out that no fossil-group had a global distribution during the Lower Permian, which was a time very much like today with polar ice and strong latitudinal gradients restricting biotic distribution. But we can still correlate using the complete "stratigraphic toolkit"!

In my perspective piece in *Permophiles* 75 I indicated that greater focus was needed on correlation with the Gondwana and boreal successions. The Sakmarian study is a start, but there is much more to do. I will do some of this during a recent collaboration set up with Gabriela Cisterna and Mercedes di Pasquo. I also look forward to seeing what the next generation of players develop as new correlation tools. They should focus on correlation and not change the definitions. The stage definitions cannot be more precise – since they focus on a single point in a rock succession. Correlation is the difficult part, and the levels of uncertainty can certainly be improved. These new players may use Bayesian statistics, artificial intelligence algorithms, and big data to improve the utility of the fossil and geochemical record. But I also think there is still more to be done on the rocks where the tremendous scales of geography and time provide inspiration.

Is all the world a stage? In some ways perhaps. Those workers who don't like the current GSSP approach may like the title "As you like it" – it suggests you are free to have your own definition on your own stage. But if we really want to understand the world view during the Permian we need stable stage definitions; in such a case the play would be called "As it is". Currently we can only correlate within part of the world for any given time – perhaps one day all the world will be a Stage.

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Stratigraphic overlap of the Lower Permian Bursum Formation and Hueco Group in southern New Mexico, USA

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Introduction

Ross and Ross (1994) proposed a Bursumian Stage for the interval that had earlier been considered the lower part (fusulinid-based substage) of the Wolfcampian Stage in the American Southwest (Thompson, 1954). This reflected a threefold division of the Wolfcampian based on fusulinids that came to be called the Bursumian, Nealian and Lenoxian substages (e. g., Thompson, 1954; Ross and Ross, 1987; Wilde, 1990; Wahlman, 2019). It was designed to solve a perceived problem based on the GSSP that placed the correlated Permian base within the Wolfcampian, at about the Nealian base. Thus, Ross and Ross (1994) removed the lower Wolfcampian from the stage so that the correlated base of the Permian would fall between stage boundaries in the North American section. Nevertheless, this was really not necessary, as the North American stages are provincial chronostratigraphic units, not the so-called global stages (Gzhelian, Asselian) relevant to placement of the base of the Permian.

When Ross and Ross (1994) defined the Bursumian stage they had no stratigraphic or biostratigraphic data of their own to present, but instead referred to the stratigraphic and biostratigraphic data in Thompson (1954). In the late 1990s, we began (with James Barrick and the late Garner Wilde) to look at the Bursum Formation in detail across its outcrops in New Mexico. The result of more almost 30 years of research has been to obtain detailed lithostratigraphic, petrographic and biostratigraphic data on the Bursum Formation and related strata across New Mexico (see Lucas and Krainer, 2004 and Krainer and Lucas, 2009, 2013 for summaries of much of our work). That work also indicated that the Bursum Formation and its fusulinid record are not suitable for stage (or substage) definition, and Wilde (2002) proposed the Newwellian as the lower Wolfcampian substage (also see Lucas et al., 2017a).

Here, we report a solution to a problem with the age of the Bursum Formation first identified by Lucas et al. (2017b). This problem arose in the Little San Pascual Mountains in southern New Mexico (Fig. 1), where Barrick (in Lucas et al., 2017b) identified Sakmarian conodonts in the upper Bursum Formation. This is a younger age than was thought to be indicated by other biostratigraphic data from the Bursum Formation, which suggested it was no younger than Asselian. The solution to this problem seems to lie in the fact that in and near the keel of the Orogrande basin (Fig. 1), Bursum deposition lasted longer than the "Bursumian," as the upper Bursum Formation contains Nealian fusulinids and Sakmarian conodonts not found elsewhere across its outcrop belt.

Stratigraphic context

In southern New Mexico, mostly on the White Sands Missile Range (WSMR) in Socorro, Sierra and Doña Ana counties, the Bursum Formation is exposed in the Oscura Mountains and San Andres Mountains (those mountain ranges are separated by Mockingbird Gap), over a distance of approximately 120 km in a north-south direction (Fig. 1). Over that transect, the Bursum Formation shows distinct lateral variation in thickness (37 to 120 m) and facies (Fig. 2). The facies are dominantly marine in the northern part and are assigned to the Bruton Member, in which interbeds of coarse siliciclastic sediments (conglomerate, sandstone) are very rare or absent. The facies of the Bursum Formation to the south at Rhodes Canyon (and Hembrillo Pass) differ from the sections farther north in consisting of an entirely siliciclastic lower part (that resembles the Laborcita Member to the east) and an upper part composed of shale and thick limestone intervals (Fig. 2). Farther south, at Ash Canyon, the Bursum Formation has either pinched out or is equivalent to strata in the upper part of the Panther Seep Formation (Kottlowski et al., 1956; Fig. 2).

Hueco Group strata are present across the San Andres Mountains as far north as Rhodes Canyon (Kottlowski et al., 1956; Lucas et al., 2024, 2025). They are limestone and shale with a few thin beds of conglomerate and sandstone (Fig. 2). Equivalent strata to the southwest (Robledo and Big Hatchet mountains) are part of the Horquilla Formation, which shows

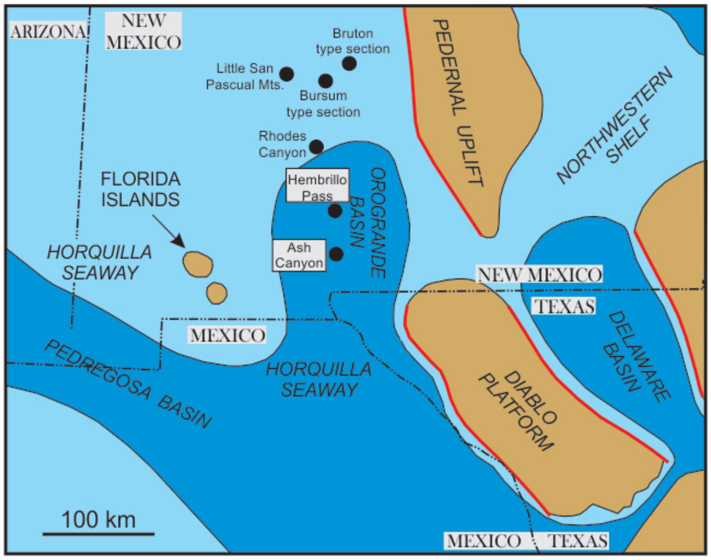

Fig. 1. Simplified paleogeographic map of southern New Mexico at approximately the beginning of Permian time. The stratigraphic sections in Fig. 2 are located on the map.

an essentially continuous depositional record of fossiliferous limestones from the Virgilian up through the middle Wolfcampian (including fusulinids and conodonts).

Stratigraphic overlap

We present a correlation of Bursum stratigraphic sections in southern New Mexico (Fig. 2) that has important implications for regional lower Permian stratigraphy and chronostratigraphy. The Bursum Formation regionally is either entirely of Virgilian age (north of Socorro County), or entirely or nearly entirely of early Wolfcampian age to the south (Lucas and Krainer, 2004; Krainer and Lucas, 2013). The base of the Hueco Group as determined by fusulinid biostratigraphy is of middle Wolfcampian age, so the Hueco is generally considered to represent a marine interval subsequent to Bursum deposition (e.g., Wahlman, 2019; Lucas et al., 2024, 2025).

However, on the WSMR a case has been made that the upper Bursum Formation in the Oscura Mountains, above the lowest occurrence (LO) of *Schwagerina*, correlates to part of the lower Hueco Group in the San Andres Mountains (Fig. 2). Kottlowski and LeMone (1994, fig. 3) first presented this correlation, indicating that the lower Bursum is stratigraphically below the Hueco base from Mockingbird Gap southward to the area between Hembrillo and Ash canyons, where it pinches out between the Panther Seep Formation (below) and the Hueco Group (above). That same diagram shows the upper Bursum correlative to part of the lower Hueco Group over the same transect.

In part, Kottlowski and LeMone (1994) based this on a correlation first suggested by Thompson (1954, fig. 5), who correlated the *Schwagerina* limestone above his type Bruton Formation section southward to outcrops north and south of Rhodes Canyon, and as far south as Cottonwood Canyon in the San Andres Mountains. However, Thompson (1954, fig. 5) indicated that these strata were not part of the lower Hueco group, and he depicted a pervasive conglomerate at the Hueco Group base across that transect that does not exist.

Nevertheless, Kottlowski and LeMone (1994, fig. 3) did include the *Schwagerina* limestone in the Hueco Group (as did Lucas et al., 2001, fig. 3, without discussion). Importantly, this limestone contains middle Wolfcampian fusulinids, notably at Hembrillo Pass and to the south (Fig. 2). Our stratigraphic and fusulinid data (see Krainer and Lucas, 2025 for more details) also support the correlation of the *Schwagerina* limestone over the transect of sections on the WSMR that indicates that the upper part of the Bursum section at the Bursum type section and in Bruton Canyon is equivalent to part of the lower Hueco Group to the south (Fig. 2).

The relevant fusulinid records are:

1.Bruton Canyon, type section of Thompson's (1942) Bruton Formation, now the Bruton Member of the Bursum Formation (Lucas and Krainer, 2004). In this section, based on identifications by the late Garner Wilde, the lower part of the Bursum Formation contains Virgilian fusulinids (*Triticites beedei*/*plummeri*) overlain by beds with T. creekensis (Lucas et al., 2022, fig, 21). The overlying *Schwagerina* limestone contains two species of *Schwagerina* and specimens of *Triticites*. Stratigraphically higher, no fusulinids are present in the Bursum Formation.

2.Type Bursum section. Lucas et al. (2000; also see Lucas and Wilde, 2000) documented the fusulinids from this section as a lower portion with *Triticites creekensis* and *Leptotriticites* species, overlain by the *Schwagerina* limestone with *T. creekensis*, *Leptotriticites*, *S. grandensis* and *S. emaciata*. Above that limestone there are no fusulinids known.

3.Rhodes Canyon. Kottlowski et al. (1956, fig. 8) placed the Hueco base at the thin conglomerate above a relatively thick limestone interval, but we include that limestone interval in the lower Hueco (Fig. 2). The type stratum of *Schwagerina andresensis* is in the upper part of that limestone interval (Thompson, 1954, fig. 7), and there are records of *S.* aff. *S. andresensis* stratigraphically higher in that section (Kottlowski et al., 1956, fig. 9).

4.Hembrillo Pass. Here, Kottlowski et al. (1956, fig. 8) reported *Schwagerina andresensis* in the basal Hueco limestone immediately overlying the Bursum Formation.

5.Ash Canyon. Thompson (1954, fig. 11) reported *Schwagerina andresensis* in the lower limestone interval of the Hueco and species of *Pseudoschwagerina* stratigraphically higher. At Love Ranch, about 30 km south of Ash Canyon, Kottlowski (1956, fig. 9) reported *Schwagerina* and *Pseudoschwagerina texana* in the basal Hueco limestone interval. The presence of *Pseudoschwagerina* is usually taken to indicate a middle Wolfcampian age (e.g., Wilde, 1990; Wahlman, 2019).

Some of these fusulinid records have not been verified by fossils described and/or illustrated in the literature, and such documentation should be undertaken. The correlation advocated here (Fig. 2) is mainly event stratigraphic in that it correlates a thick limestone interval with abundant *Schwagerina* that is at the Hueco Group base in the San Andres Mountains to a similar, *Schwagerina*-rich limestone interval just above the middle of the Bursum Formation in the Oscura Mountains and Hansonburg Hills (Fig. 2). One of the problems with the fusulinid record

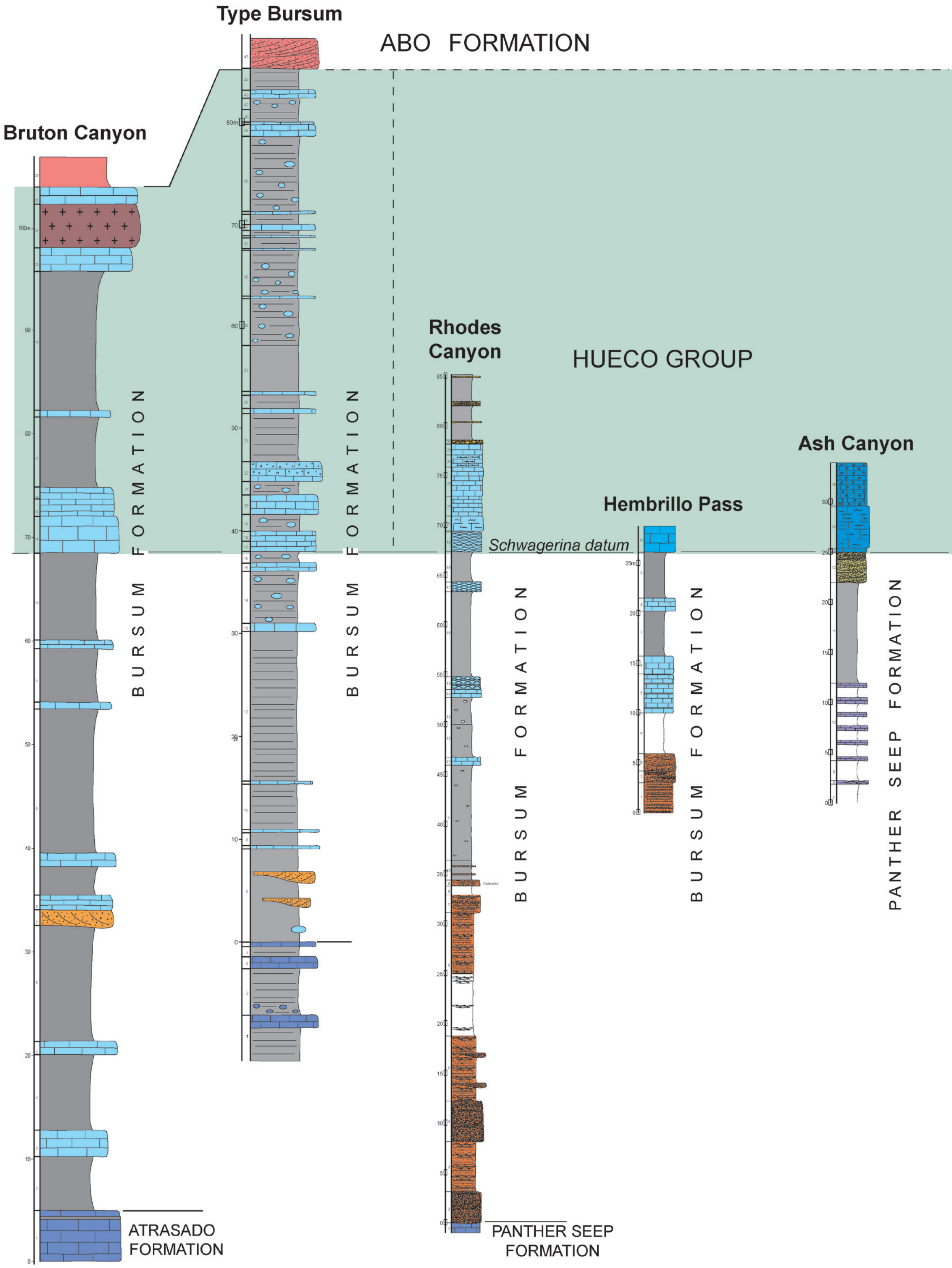

Fig. 2. Correlation of stratigraphic sections of the Bursum Formation, Hueco Group and adjacent strata in the Orogrande basin of southern New Mexico (see Figure 1 for section locations). See the text for discussion and Krainer and Lucas (2025) for more details.

here is that the LO of *Schwagerina* in these sections is a facies-controlled occurrence associated with a marine event that caused deposition of the *Schwagerina* limestone. There should be older (stratigraphically lower) records of *Schwagerina* in these sections, but the facies apparently did not favor its presence or it has not been discovered in stratigraphically lower beds.

Barrick in Lucas et al. (2017b, p. 303, fig. 11.7-11) documented conodonts from stratigraphically high in the Bursum Formation at Little San Pascual Mountain, about 50 km west/northwest of the Bursum Formation outcrops on the WSMR (Fig. 1). He judged the conodonts "surprising" because they are Sakmarian (*Sweetognathus merrilli*), which is younger than the Asselian age that had been assigned to the youngest Bursum Formation strata elsewhere.

The Little San Pascual Mountain and WSMR Bursum strata were deposited in the rapidly subsiding portion of the central Orogrande basin (Fig. 1). The conodonts and the correlation advocated here suggest that Bursum deposition may have continued longer in that part of the Orogrande basin than elsewhere. Another possible is that the likely unconformity between the Bursum and overlying Abo Formation represents a longer hiatus outside of the center of the Orogrande basin than it does in the basin.

Conclusion

We advocate correlating the upper Bursum to the lower Hueco Group on the WSMR and vicinity (Fig. 2), a correlation in need of further research and testing. This correlation does create an apparent overlap of some characteristic early Wolfcampian ("Bursumian" = Newellian) fusulinid taxa, such as *Triticites creekensis*, with the characteristically middle Wolfcampian (Nealian) *Schwagerina andresensis* and P*seudoschwagerina*. This may indicate a short overlap zone of the early and middle Wolfcampian fusulinid taxa that merits further study. This overlap reduces the clarity of the lower-middle Wolfcampian boundary based on fusulinids and provides yet another reason why "Bursumian" is not a useful chronostratigraphic unit.

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Palaeotemperature and palaeoprecipitation modelling in Earth Explorer: a useful aid for Permian stratigraphers and palaeontologists

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Introduction

Recent palaeotemperature and palaeoprecipitation modelling (Li et al., 2022) implemented by the Earth Explorer Deep-time Digital Earth tool superimposed on palaeogeographic maps allows a detailed analysis of palaeoclimate variability in precipitation and temperature without specialist software, and on a simple laptop. The Earth Explorer Deep-time Digital Earth tool can also be used in a more sophisticated way to build user models. For example palaeogeographical fossil occurrence data can be plotted on detailed palaeogeographic maps with palaeotemperature and palaeoprecipitation modelling to allow comparisons to be made between fossil assemblages and palaeotemperature and palaeoprecipitation. For simple illustration and visualisation purposes, Earth Explorer provides excellent maps and images that can be used by students and faculty alike.

The palaeoclimate part of Earth Explorer uses the data and visualisations of Li et al. (2022). Li et al. (2022) produced an open access climate dataset of 55 snapshot simulations for the past 540 million years, with a 10-million-year interval, using the Community Earth System Model version 1.2.2 (CESM1.2.2). The climate simulation dataset includes global distributions of monthly surface temperatures and precipitation, with a 1° horizontal resolution of 0.9° × 1.25° in latitude and longitude. The PaleoDEM and points/polyline/polygon (rotation and geometry files) of Scotese and Wright (2018) or the GPlates Plate Model data can be used. Temperatures shown are annual mean surface temperatures, and precipitation is annual mean precipitation converted to mm/day (see Li et al. 2022).

Example 1: palaeotemperature along two lines of longitude

A simple exercise can illustrate some of the useful functions of the modelling. In this case I chose to make a comparison of the changes in palaeotemperature along two lines of longitude, 40°E and 140°E across the southern hemisphere from the equator to the south pole (Figs. 1 and 2) in the Asselian. The southern hemisphere longitude at 40°E is interesting because it is dominantly a terrestrial transect through the western Tethyan through what is now Arabia, and south into India. The model allows the user to pinpoint positions on the paleogeography map and provide spot palaeotemperature figures for those positions (and their accompanying palaeolatitude and palaeolongitude). The profile of annual mean surface temperatures for this transect is shown in Fig 1a and illustrates the positions on the line of longitude where the palaeotemperature gradient is highest and lowest. It also indicates the palaeolatitude at which annual mean surface temperatures go below zero. This kind of analysis could be very useful comparing, for example, palynological or palaeobotanical assemblages of the Asselian in Indian and Arabia. Any assemblage differences along a time slice may be due to palaeotemperature.

A similar analysis is shown for a 140°E transect (Fig. 2) which passes again through terrestrial environments at least in its southern part in Australia and Antarctica. The same comparisons would also be possible. Comparisons of rates of

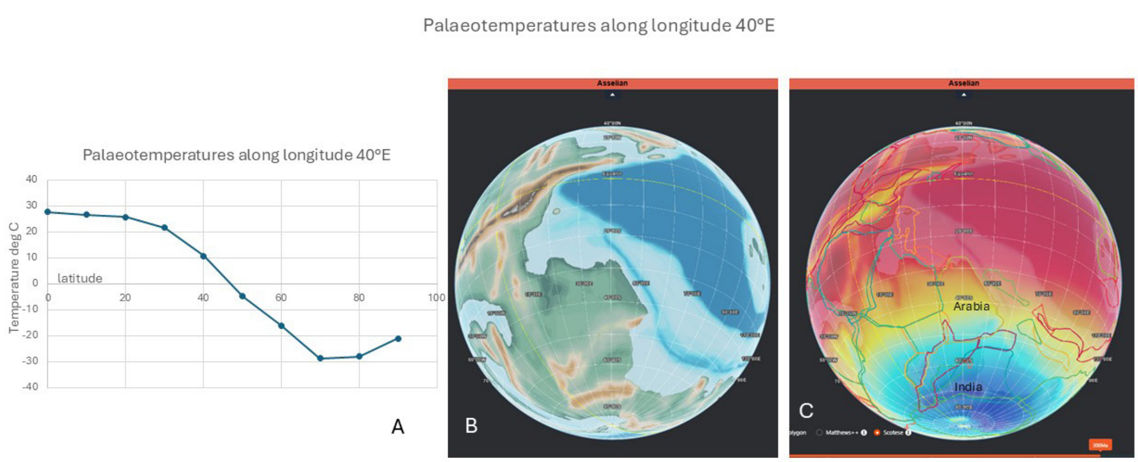

Fig. 1. Palaeotemperature modelling for 40°E across the southern hemisphere from the equator to the south pole. **A**. Palaeotemperature profile; **B**. Palaeogeography; **C**. Palaeotemperature modelling from Li et al. (2022).

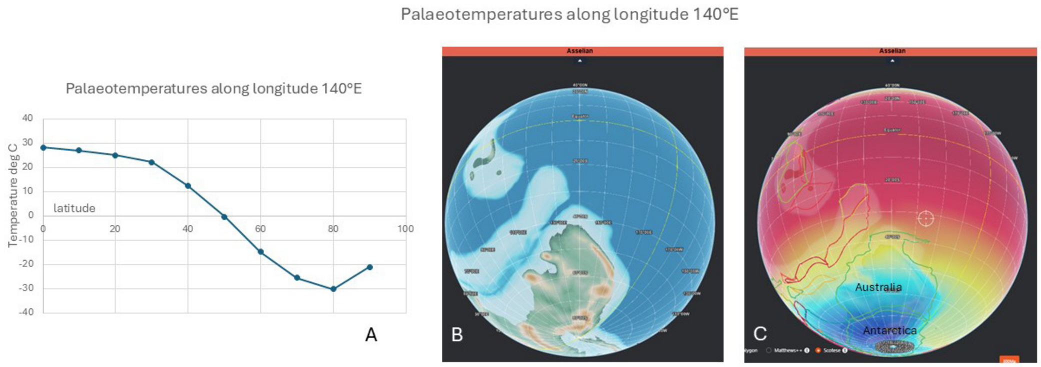

Fig. 2. Palaeotemperature modelling for 140°E across the southern hemisphere from the equator to the south pole. **A**. Palaeotemperature profile; **B**. Palaeogeography; **C**. Palaeotemperature modelling from Li et al. (2022).

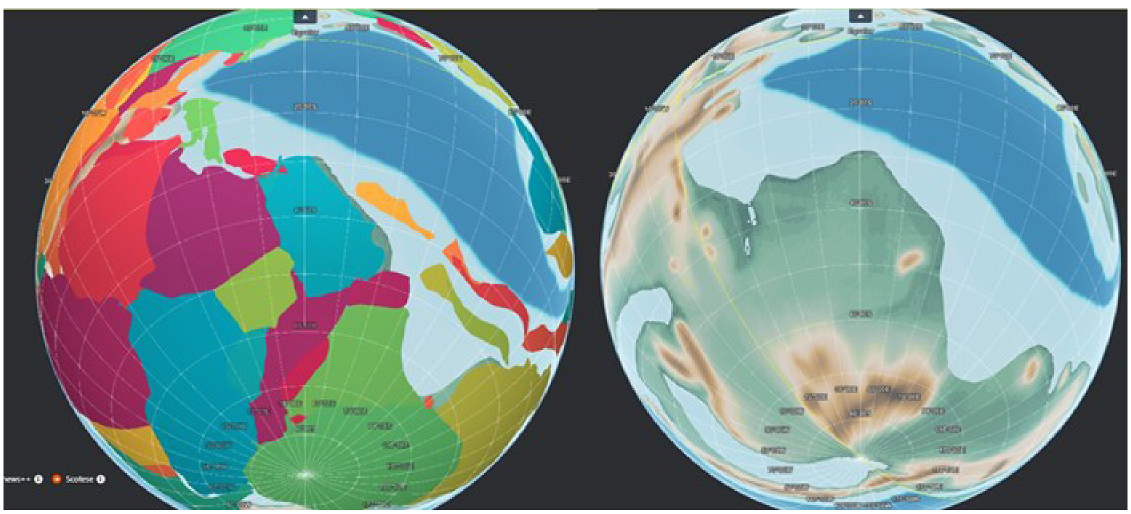

Fig. 3. The Serpukhovian/Bashkirian palaeogeography in DDE Earth Explorer and the structural makeup of the region from Scotese and Wright (2018).

palaeotemperature change with latitude for the two transects can also be made looking at Figs. 1 and 2.

Example 2: palaeoclimate across the Arabian region in basins following Hercynian tectonism

This next example considers how palaeoclimate varies across the Arabian region in basins following Hercynian tectonism – and how this affected sedimentary facies. Again the Earth Explorer tool is very useful.

Interpreting the Arabian sub-crop pattern beneath the Hercynian unconformity, Faqira et al. (2009) defined three major Hercynian arches in the Arabian Plate: the Levant, the Al Batin and Oman-Hadhramaut arches, separated by two large basins in which the pre-Hercynian section (Cambrian – Devonian) is generally preserved, and further overlain by Carboniferous to Cisuralian clastic sedimentary rocks, which include the Unayzah Formation in Saudi Arabia, the Al-Khlata and Gharif formations in Oman, the Kuhlan and Akbhara formations in Yemen, and the Ga'ara Formation in Iraq.

Earth Explorer allows a Serpukhovian/Bashkirian palaeoclimate profile through the Gondwana to Tethys margin at the approximate age of the peak of Hercynian activity in the Arabia region (see Stephenson 2024; Stephenson et al. 2017). Fig. 3 illustrates the palaeogeography of the time. The highland areas in the SE of the Arabian region presumably relate to the triple-junction highland area in Oman proposed by Al-Belushi et al. (1996).

Palaeoclimate modelling based on first principles physico-climatic and topographic data from Li et al. (2022) visualised in Earth Explorer shows the 0°C palaeoisotherm which theoretically confines the glacially-influenced sedimentation to the south (Fig. 4). This seems to correspond with the present day distribution of the glacially influenced Al Khlata Formation in Oman, the Kuhlan and Akbarah formations in Yemen (Stephenson et al. 2012), as well as the more southerly occurrences of the glacially-influenced Unayzah B and C units in southern Saudi Arabia. The 0°C palaeoisotherm tends not to support glacially influenced sedimentation further north in Saudi Arabia around Ghawar, for example as advocated by (Melvin and Sprague 2006), at least in the Serpukhovian/Bashkirian.

Glacially influenced sedimentary rocks are well known to provide the reservoirs (diamictite, glaciofluvial and glaciodeltaic sandstones) for petroleum, often sourced in the Arabian Palaeozoic by Lower Palaeozoic hot shales. Thus palaeotemperature variation places a useful theoretical boundary for the development of glacially influenced sediments. The

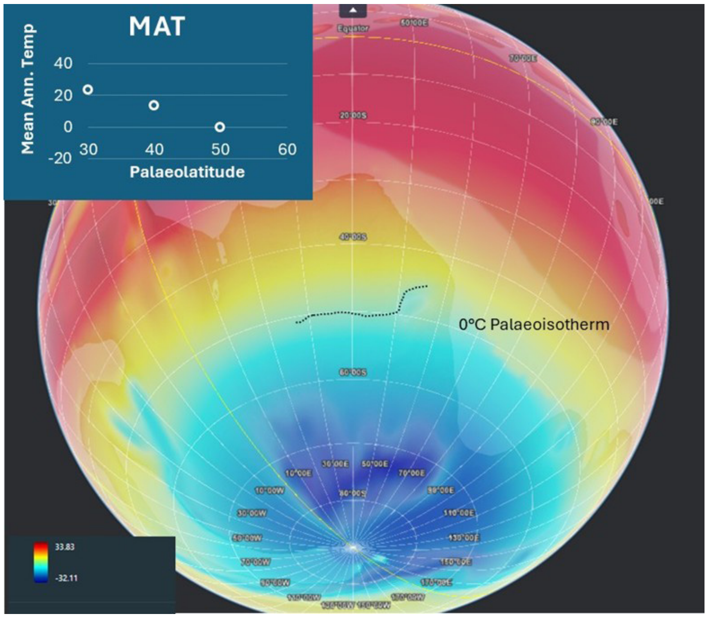

Fig. 4. Serpukhovian/Bashkirian mean annual surface temperature (MAT) in °C; 0°C palaeoisotherm and trend of MAT with palaeolatitude, along palaeolongitude 40°E

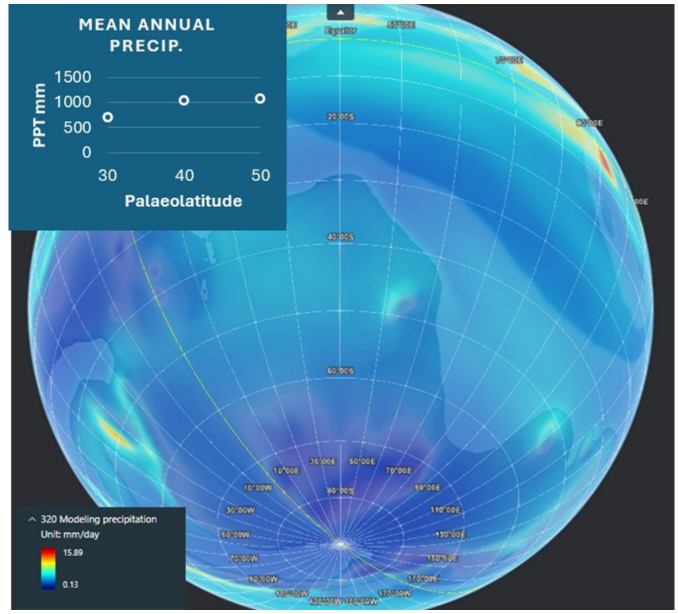

Fig. 5. The variation in precipitation from north to south through the region from around 700mm in the north (palaeolatitude 30°C) to higher amounts in the south (>1000mm). Inset shows palaeoprecipitation profile along palaeolongitude 40°E.

variation in palaeoprecipitation (Fig. 5) perhaps also provides some input to facies types within clastic palaeoenvironments, which in the Arabia area in the Serpukhovian/Bashkirian would have ranged from relatively wet environments in the south, to potentially semi-arid environments in the north. This obviously had a strong influence on palaeovegetation (see Stephenson 2024,2025).

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New excavations at the extraordinary 290 Ma-old Bromacker fossil lagerstätte (Tambach Formation, Germany): when cutting-edge research meets science communication

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Introduction

The Bromacker sandstone quarries of the Cisuralian age (Tambach Formation, Thuringia, Germany) are well-known for their excellently preserved tetrapod footprints since 1887 (Pabst, 1895). Until 1908, footprints and other trace fossils from this locality were extensively studied by Wilhelm Pabst, curator of the natural history collections of the Herzogliches Museum Gotha (e.g., Pabst, 1908) and were the later subject of numerous studies (e.g., Müller, 1954; Haubold, 1972, 1998; Fichter, 1998; Voigt and Haubold, 2000; Voigt et al., 2007; Romano et al., 2016; Marchetti et al., 2018, 2024a). However, it was only after the first bone discovery in 1974 by Thomas Martens, curator of the geological collections of the Museum der Natur Gotha from 1978 to 2015, that systematic excavations started. From 1993 to 2010 annual excavations, led by the Museum der Natur Gotha and the Carnegie Museum of Natural History, Pittsburgh, were performed. Bromacker became the most important fossil lagerstätte for Cisuralian tetrapods outside of North America (e.g., Berman et al., 1998, 2000a; 2004; 2013; 2020; Nyakatura et al., 2019). After 10 years of stasis, excavation activities at Bromacker were restarted in the frame of the five-year BROMACKER project (2020-2025), funded by the German Federal Ministry of Research and Education. The aim of this project is a multidisciplinary research approach coupled with innovative communication and public engagement activities, allowing the public to be closer to the scientific research. The Museum für Naturkunde Berlin – Leibniz Institute for Evolution and Biodiversity Science, the Friedenstein Stiftung Gotha, the Friedrich-Schiller-Universität Jena and the UNESCO Global Geopark Thüringen Inselsberg –

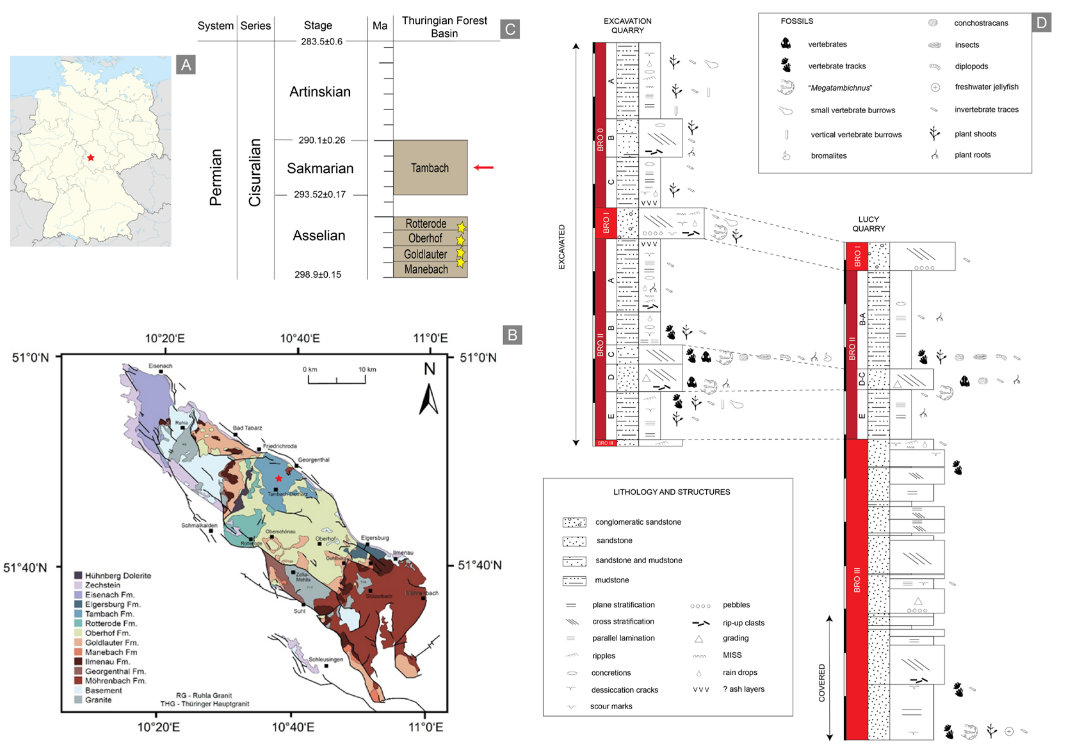

Fig. 1. Stratigraphy of the Tambach Formation and the Bromacker locality. **A**. Location of the Bromacker locality in Thuringia, Germany. **B**. Location of the Bromacker locality in the Thuringian Forest Basin. **C**. Chronostratigraphic scheme indicating the age of the Tambach Formation. Yellow stars represent radiometric ages. **D**. Stratigraphic log of the Bromacker locality, scale in m.

Drei Gleichen are cooperating for this purpose. The data utilised in the frame of this project are analysed using innovative methods and a strongly multidisciplinary approach, that yielded relevant results (e.g., Buchwitz et al., 2021; Marchetti et al., 2021, 2024b, 2025; Pint et al., 2023; MacDougall et al., 2024; Ponstein et al., 2024) and are going to be published also after the official end of the project. Between 2020 and 2025, the international project team was conducting six excavations in cooperation with Thomas Martens, resulting in new data highly relevant to palaeontology and stratigraphy. The purpose of this contribution is to provide an overview of these excavations as regards methods and results as well as the potential outcome for scientific research and science communication.

Stratigraphy and fossil content

The Bromacker locality is part of the continental Tambach Formation, an approximately 200-280 m thick unit deposited in the late Carboniferous-Permian Thuringian Forest Basin of Thuringia, Central Germany (e.g., Eberth et al., 2000; Menning et al., 2022) (Fig. 1). This unit has an erosive base on the underlying units, including the Rotterode, Oberhof and Goldlauter Formation. It is divided into three members, from the base to the top: a lower conglomerate (Bielstein Member, 40-125 m), a middle unit with sandstones and mudstones (Tambach Sandstone Member, 40-110 m) and an upper conglomerate (Finsterbergen Member, 10-50 m) (Lützner et al., 2012). The Bromacker locality belongs to the upper part of the Tambach Sandstone Member, a unit characterised by red beds representing fluvial to floodplain deposition (Lützner et al., 2012). The Bromacker locality is situated between the villages Tambach-Dietharz and Georgenthal and is part of the UNESCO Global Geopark Thüringen Inselsberg – Drei Gleichen (Fig. 1A-B). It is constituted by inactive quarries extending for about 1 km2, named Seeberger Fahrt, Raab, Lucy, commercial and excavation quarries (e.g., Eberth et al., 2000; Martens et al., 2009). In these quarries, a succession about 16 m thick has been exposed (Fig. 1D). The lower 7 m consists of thick and tabular fluvial sandstones alternated with thin laminated mudstone intervals. Most of the trace fossils were found in this stratigraphic interval (e.g., Pabst, 1908; Müller, 1954; Haubold, 1972, 1998; Voigt et al., 2007; Marchetti et al., 2025). This part of the succession is nowadays partly exposed in the Lucy and commercial quarries. The overlying ~ 4 m of the Bromacker succession are constituted by laminated mudstones interbedded with fine-grained, cross-stratified sandstones. The laminated mudstones include invertebrate burrows, conchostracans and rare tetrapod footprints, plants and arthropod remains (e.g., Martens et al., 1981; Voigt, 2005). The fine-grained sandstone yields mainly bone remains and vertebrate burrows (Eberth et al., 2000; Marchetti et al., 2024b). This part of the succession is exposed in the Lucy and excavation quarries. Towards the top of this interval, a potential thin cinerite layer was found in the frame of the 2025 excavation. This is overlain by a thick package of cross-stratified, conglomeratic fluvial sandstone, which includes tetrapod and invertebrate burrows (Marchetti et al., 2024b). The excavations in 2022-2024 uncovered the uppermost 4 m of the succession, overlying this sandstone package. It is a sequence of laminated mudstone and cross-stratified fine-grained sandstone with a potential thin cinerite layer towards its base. This interval includes mostly invertebrate burrows and plant remains.

The abundance and quality of preservation of the tetrapod trace fossil material made Bromacker and the Tambach Formation worldwide known and a reference for Permian tetrapod ichnology (e.g., Voigt, 2005; Marchetti et al., 2024a, 2025) (Fig. 2). This includes exquisitely preserved footprints of *Ichniotherium*, *Dimetropus*, *Varanopus* as well as body and scale impressions, including the earliest evidence of epidermal scales and body impressions of Synapsida (Marchetti et al., 2025) (Fig. 2C). Also, the unique co-occurrence with vertebrate skeletons permitted detailed track-trackmaker correlations (e.g., Voigt et al., 2007). Furthermore, the abundance, articulation and completeness of the skeletal material made Bromacker known worldwide as a vertebrate body fossil locality (e.g., Berman et al., 2004, 2020; Nyakatura et al., 2019; Ponstein et al., 2024) (Fig. 2A-B). The vertebrate ecosystem was diverse and numerically dominated by diadectids (Fig. 2B), so it was the first example of a modern trophic ecosystem (MacDougall et al., 2022). Moreover, the earliest evidence of facultatively bipedal reptiles have been proposed (Berman et al., 2000b), and there is also evidence of fossorial animals (MacDougall et al., 2024) (Fig. 2A). As regards palaeogeography, depositional setting and climate, this locality was situated in an inland area at low latitudes of Pangaea, and the climate was strongly seasonal, as inferred by multiple proxies including contour marks (e.g., Pint et al., 2023) (Fig. 2D).

The Tambach Formation maximum age is based on radiometric dating (Lützner et al., 2021) on underlying volcanic units within the Rotterode (295.8 ± 0.4 Ma) and the Oberhof Formation (296.8 ± 0.4 Ma; 296.9 ± 0.4 Ma) (Fig. 1C). The minimum age is currently based on the biostratigraphy of skeletons, footprints, blattoids and conchostracans and suggests a probable Sakmarian age (Marchetti et al., 2022; Menning et al., 2022).

Excavation methods

The BROMACKER project was scheduled between August 2020 and December 2025. An essential part of the project were the annual excavations in the excavation quarry (Eberth et al., 2000), part of the Bromacker lagerstätte. The first excavation lasted two weeks, the second to the fifth excavations four weeks and the sixth excavation three weeks.

Fig. 2. Significant fossils and sedimentary structures. **A**. The recumbirostran *Bromerpeton subcolossus* MacDougall et al., 2024. **B**. The diadectid *Diadectes dreigleichenensis* Ponstein et al., 2024. **C**. The resting trace *Bromackerichnus requiescens* Marchetti et al., 2025. **D**. Contour marks, mud cracks and footprints of *Ichniotherium sphaerodactylum*, convex hyporelief. The pictured scale bars are 5 cm long.

Establishment of a protocol

The first excavation was conducted in October 2020. No digging had been performed in the previous 10 years. In the first step, the weathered rock material consisting of clayey siltstone was removed from the top of one of the selected excavation sites to expose a continuous, non-weathered surface, which was considered the new excavation base level, similar to the previous excavation base level (Eberth et al., 2000).

Afterwards, this area was divided into excavation sectors of similar size, named WEST, MIDDLE and EAST. Later during the 2020 excavation, EAST+ was added because of the expansion of the excavated area towards east due to a bone finding (Fig. 3B). In the 2021-2025 excavations, further sectors were added in all the newly excavated areas. Often, discontinuities such as vertical fractures in the rock were used as a reference to set the sector boundaries.

Additionally, layer packages characterised by specific lithofacies were defined (Figs. 1, 3A): an up to 80 cm thick sandstone layer labelled BRO I represents the top of the quarry section. All layer packages immediately below BRO I consisting of fine-grained sandstone, siltstone and claystone in an about 4 m-thick sequence were defined as BRO II and further divided into BRO II A to E (Figs. 1, 3A). The excavations in 2022-2024 uncovered a 4 m thick interval above BRO I, that is located outside but near the excavation quarry, named BRO 0 and vertically divided in three parts (BRO 0 A-C) (Fig. 1). Moreover, the track-bearing sandstone layers, mostly exposed in the Lucy and commercial quarry stratigraphically below BRO II, were named BRO III (Fig. 1).

For lack of electronic survey devices in 2020, the excavation members measured the location of the findspots with a tape to get approximate coordinates to infer the vertical and horizontal

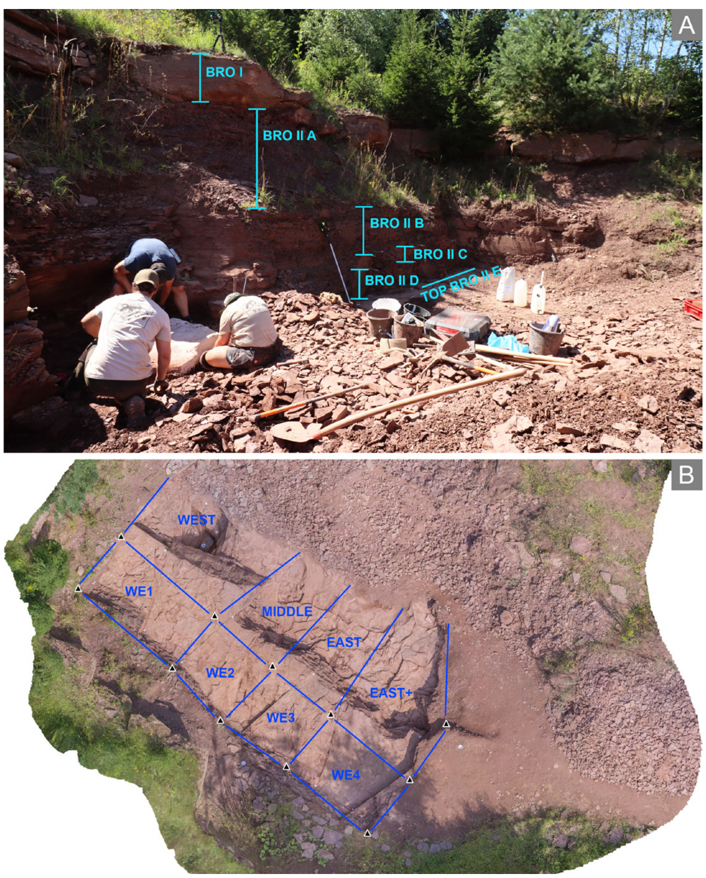

Fig. 3. Layer packages and excavated sectors. **A**. Division of the northwestern excavation area into layer packages BRO I to BRO II E in a photo of the field jacket building taken on the second last day of the excavation in 2023. **B**. Excavated sectors of the northwestern excavation area, orthophoto generated after the 2021 excavation.

Fig. 4. Photo documentation of a find in the second extended southeastern excavation area in 2025. **A**. The freshly extracted specimen with two measuring targets on the topside of the fossil slab and its counterpart next to it, a north arrow scale and a specimen label, in top view. **B**. The findspot from a distance with the specimen in focus. **C**. A finger pointing at the imprint of a tooth in the specimen counterpart.

Documentation protocol

During the first excavation, it became obvious that the goal of the project-related excavations to document all finds as comprehensively as possible would require a more advanced documentation system. With this in mind, SK and LM developed a system for the procedure of documenting finds in preparation for the excavation of 2021.

SK was the main responsible for the documentation of the project finds. Nevertheless, it had to be assured that all excavation members would be able to conduct the documentation of a find. Simultaneous digging in different areas of the quarry made this necessary. So, all the excavation members got an introduction to the digging and documentation procedure at the beginning of each excavation.

For the written documentation of the single finds, a field table was generated. Among other information, the fossil category and the running number were noted in this table. All finds got a running number separately in each sector and independently of the fossil category. The year of the find, the lithological unit, the layer package, the sector, the fossil category and the running number were written on the paper label of each specimen. Starting from the excavation 2022, the specimen labels were preprinted to facilitate a correct labelling.

For the photo documentation rules were defined, too. The guideline for the visual documentation was to take specific photos of each find: one close-up of the specimen in situ at its findspot with its label, a scale, total station targets and a north arrow template or compass, and up to three overview photos with the findspot, the surrounding area and the specimen in focus (Fig. 4).

All documentation steps, instructions and information were put together in a manual. Furthermore, an overview with photos of fossils and sedimentary structures characteristic for the Bromacker locality was generated. Both documents were printed and made available to all excavation members during the digs. Every year the documentation system became a bit more precise, and the manuals for the excavation members were updated accordingly. The photographic fossil overview was frequently expanded by additional fossils and sedimentary structures.

A total station (Leica Flexline TS06 Plus) was bought in 2021 (Fig. 5). This professional survey device, once georeferenced with previously measured high-precision GPS points, generated georeferenced coordinates of the findspots of the excavation finds. Two members of the Bromacker team were responsible for this device. They operated it and taught interested excavation members its handling. This enabled them to operate it as well. Also, a manual was produced and made available during the digs. Starting from 2021, this device was used during every excavation and provided reliable measurement results.

Since the start of the new excavations, the areas to be excavated were divided into sectors for a better understanding of the areal distribution of fossils and facies (Fig. 3B). The segmentation of the sites turned out to be a necessity to coordinate excavation members in view of the find documentation. Generally, one to three people were working in each sector. Every sector group had its own box containing field tables, labels, targets for measuring the findspots and further utensils to be able to work independently. The cameras for the visual documentation were shared among the team members.

Detailed stratigraphic logs

Between 2022 and 2025, the excavations were not only focused on finding fossils but also on a detailed analysis of the lithological sequences, more precise than the lithofacies-based layer package classification of the Bromacker site. Few sectors were selected for this purpose every year. LM, SK and further selected team members were analysing and identifying lithological units while digging down. This work was accompanied by a special documentation system consisting of the

Fig. 5. Total station data acquisition. **A-C.** Measuring a findspot via total station. **A**. One person holds the reflector staff, that is placed on a measuring target on the topside of the find, upright; **B**. the other person targets the centre of the prism via total station and **C**. pushes a button so that the targeted point is measured. **D**. The measured points can be visualised in a geographic information system software: all findspots in the northwestern excavation area of the dig in 2022 are plotted in an orthophoto generated on the last excavation day. The different colours represent the six sectors the respective finds were exposed in. Photos courtesy of Anastasia Voloshina (B-C) and Peter Rohde (D).

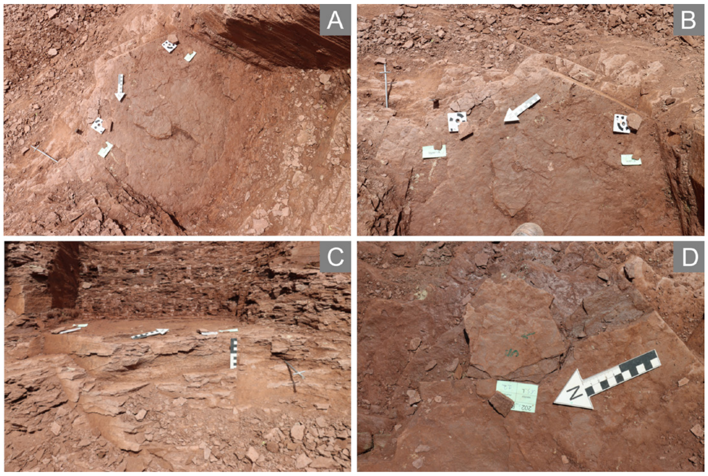

Fig. 6. Photo documentation of a lithological unit in the northwestern excavation area in 2025. **A**. The topside of the unit with two measuring targets and their inherent labels plus a north arrow in top view. **B**. Enlargement of A. **C**. The vertical section of the unit. **D**. The rock sample of the unit with a north arrow and a specimen label next to it.

following steps for each excavated interval: measuring two points on its top surface via the total station, selecting one characteristic rock sample, noting all sedimentary features in the field table and photographing the top surface and the vertical section of it (Fig. 6). Fossils and sedimentary structures found within were documented in the same way as in all other sectors. The goal of these excavations focused on lithology was to obtain more detailed stratigraphic logs of different areas within the quarry, combined with the documentation of related fossils and sedimentary structures. This will help clarifying in which depositional environment different kinds of fossils were preserved and which taphonomic processes favoured their preservation. Another goal was a stratigraphical and sedimentological correlation between the different logs. Moreover, the stratigraphic boundaries between the main layer packages have been traced throughout the excavation site and measured with multiple points via the total station to provide further data for a 3-D reconstruction of the sedimentary bodies.

Specimen collection

Excavating rock sequences at the Bromacker locality required some physical effort. Especially the layer package BRO II D consists of cross-stratified, fine-grained sandstone layers that are not easy to remove and split manually. Different kinds of chisels as well as sledge and geological hammers were the main digging tools. Unfortunately, most of the bone specimens are preserved in BRO II D.

During the excavation campaigns, seven field gypsum jackets were built to prevent skeleton parts from being damaged during their extraction and transport afterwards (Fig. 7). Since most of these finds were located in the unit BRO II D, the jacket construction and removal were quite effortful. In some cases, a diamond rock saw was needed to cut the edges of the rock blocks that were supposed to be extracted. In most cases, the largest part of the bones was not visible on the surface. Hence, the only clue preparators had were the bones visible on the rock surface. Based on this, they had to decide how large the jackets should be.

Fig. 7. Gypsum jacket building and extraction. **A**. Creation of the first field jacket in 2021 by using pieces of paper towel and liquid gypsum layer by layer. **B**. A finished jacket from 2022, still partly attached to the rock. **C**. Entire detachment of a jacket from 2022 by using several crowbars on different sides of the jacket. **D**. Placing of a jacket from 2022 on a pallet laying on its topside right after its detachment. Photos courtesy of Thomas Martens (B-D).

As soon as this decision was made, the rocks outside of the area containing the bone material had to be removed. At the end, only the bottom of the rock block was still attached to the ground. One by one multiple layers of paper pieces impregnated with liquified gypsum were added to the block until all its parts apart from its bottom were covered by a thick layer of gypsum (Fig. 7A-B). After the drying of the gypsum, the detachment process started: by using crowbars and hammers all around, the bottom of the jacket was being progressively detached from the underlying ground. To get it ready for transportation, the jacket was flipped lying on its frontside and then placed on a pallet (Fig. 7C-D).

An important part of the specimen handling in the field was their cleaning. The layer packages BRO II A to E contain clay minerals in different quantities (D contains the merest). Especially A and B are characterized by high clay concentrations as they consist of mudstone sequences with silty components. Once dried up, these rocks cannot be wet again without crumbling. This effect is caused by the swelling of these clay minerals as soon as they become wet. Based on this knowledge, dirty specimens from the clay-rich layers were cleaned with water right after their extraction.

Excavation results

Excavated areas and specimens

Through the excavation years of the new project, the appearance of the Bromacker quarry and the surrounding area was changing massively (Fig. 8). In 2020, there were two areas partly dug in the quarry as a result of the old excavations: one in

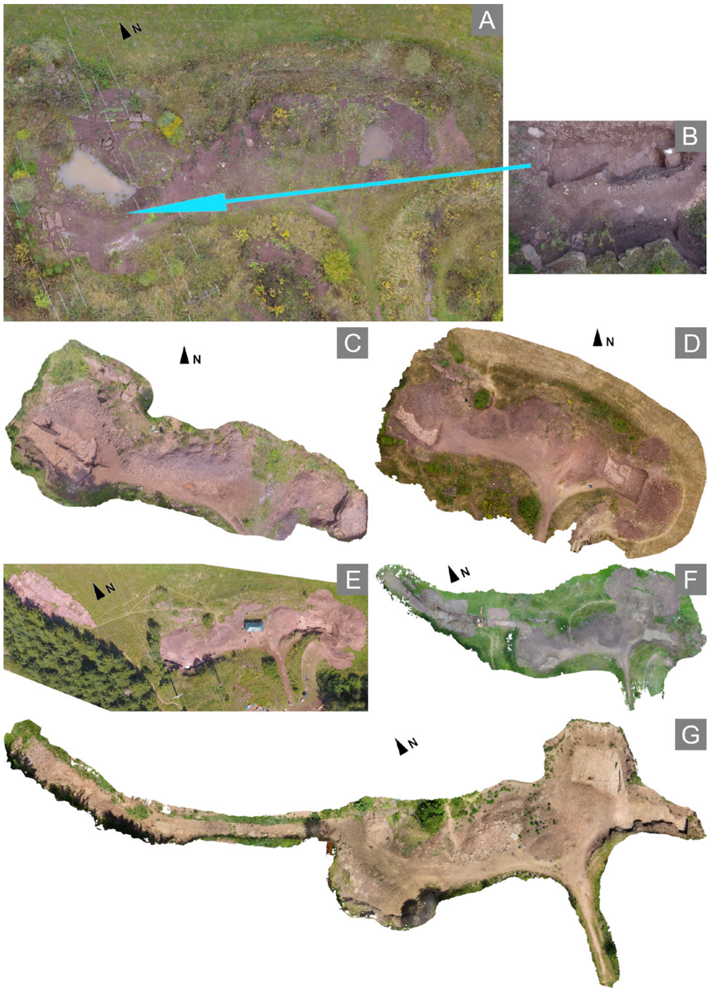

Fig. 8. Orthophotos of the Bromacker excavations between 2020 and 2025. **A**. Orthophoto of the quarry shortly generated before the excavation start in 2020 with the two former dig sites in the northwest and in the southeast of the quarry marked by the two pools visible in the photo. **B**. The new dig site of 2020 with sectors WEST (on the left) to EAST+ (on the right). **C**. The northwestern dig site extended during the excavation in 2021. **D**. The northwestern and the new southeastern dig site in 2022. **E**. The northwestern and the southeastern dig site and the new one north of the quarry in 2023. **F**. The extended northwestern, the already existing and the new southeastern dig sites plus the extended one north of the quarry in 2024. **G**. The northwestern, the older southeastern and the newer extended southeastern dig sites plus the dig site north of the quarry in 2025. The orthophotos shown in (B) to (G) were generated on the last excavation day each. Photos courtesy of Peter Rohde (A-E) and Jakob Stubenrauch (F-G).

the northwestern and one in the southeastern area of the quarry. The project team focused on the northwestern area in 2020 and 2021. In 2022, the dig in this area was continued, simultaneously a dig in the southeastern area was started. Both sites were extended between 2023 and 2024. In addition, the project team decided in 2023 to open a completely new dig site northwest of the already existing quarry. In 2024, the two sites in the quarry were expanded by a new site close to the southeastern one. As a result of this, the excavation members were digging in four different sites in 2024 (16 sectors) and 2025 (16 sectors).

The increase of sectors required an increase of excavation members. The excavation in 2020 was conducted by 14 people. Instead, 17 to 24 people per week were involved in the excavations from 2021 to 2025. In total 91 excavation members from different countries participated in the six digs of the

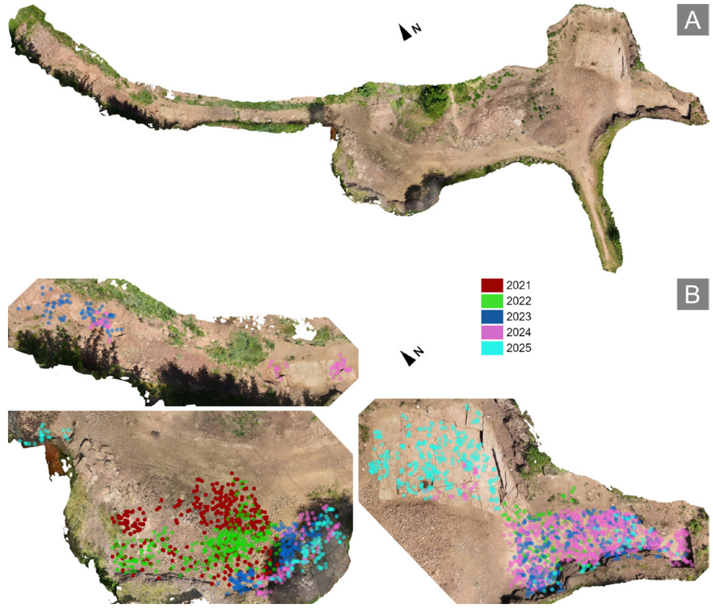

Fig. 9. Excavated area and excavated finds. **A**. Orthophoto from 2025. **B**. Selected quarry areas of the orthophoto from 2025, showing all excavation finds from 2021 to 2025, differently coloured according the year they were found in.

BROMACKER project comprising project members, students from several universities and additional people interested in palaeontology.

1816 specimens were documented during the six excavations (Fig. 9). Regarding the number of specimens per year the peak was reached in 2022 when 383 specimens were documented. Not all fossils and sedimentary structures were taken along. For instance, in some cases it was only relevant to know the location of certain horizons, such as layers containing mass accumulations of conchostracans. Finds that were not only documented but also taken along were brought to the geoscientific collection of the Friedenstein Stiftung Gotha (MNG). There, the respective specialists of the project team performed more detailed analyses of the collected material. Specimens that were not sorted out after this inspection were inventoried by SK. 770 specimens became part of the MNG collection. Further post-excavation tasks of SK were the digitalisation of the field tables resulting in Excel files, that include all available field data and additionally the total station measurements, and the writing of the annual excavation report.

Excavation highlights

During the six excavations of the BROMACKER project, abundant fossils and sedimentary structures were being extracted. Findings of bones, invertebrates, plants as well as trace fossils of vertebrates and invertebrates proved once again the existence of a diverse early Permian ecosystem at the Bromacker locality. In the following section, selected finds worth to be mentioned because of their potential scientific interest are shortly reported (Fig. 10).

In 2020, a closer look at a sandstone slab and its counterpart, that had been broken off the BRO I sandstone interval before the excavation, revealed well-preserved structures that turned out to be small tetrapod burrows with scratch traces about 1 mm wide. Another highlight of the 2020 excavation is an assemblage of isolated bones and teeth in layer package C in the EAST sector. As a result of this discovery, the excavation section was enlarged towards east (EAST+). Indeed, a high density of bones was found in the same stratigraphic level of the new sector. This bone material is relevant for taphonomic analyses of the site (Buisson, 2024). At the end of the first excavation, relatively large structures representing tetrapod scratch traces (up to 2,5 cm wide) at the bottom of large burrows were uncovered within the upper part of layer package D in sector EAST (Fig. 10A). These trace fossils were already known and informally named "*Megatambichnus*" isp. by Martens (2001). Nevertheless, it was with the BROMACKER project that it became the subject of thorough research (Marchetti et al., 2024b, 2024c).

In 2021, the first field jacket containing a semi-articulated skeleton of a diadectid was constructed and extracted (Fig. 10B). This specimen comes from sector EAST and level BRO II D. The main highlight of this field season was the finding of two slabs with bone content in layer package C in sector WE3. The preparation and subsequent CT scan brought to light an assemblage of small bones. This specimen represents a regurgitalite (Rebillard et al., 2024). It is the only finding of this kind from the Bromacker locality so far. Concerning the stratigraphy of the site, an important goal was reached in 2021: the completion of the stratigraphic log of the quarry that was started in 2020 (Fig. 1D). This section comprised all layer packages from BRO I to the top of BRO III. The top BRO III could be only reached at a small spot in sector WEST, but it allowed a correlation of this horizon with the nearby quarries. "*Megatambichnus*" isp. remained a topic of interest: in addition to the new abundant finds in the excavation quarry, an already known cluster of these structures was uncovered and studied in the Lucy quarry. These nine separate structures on the same stratigraphical level were already discovered in 2008. They are located at the transition zone between layer packages BRO II D and E and were excavated in the Lucy quarry by Martens and his colleagues decades ago.

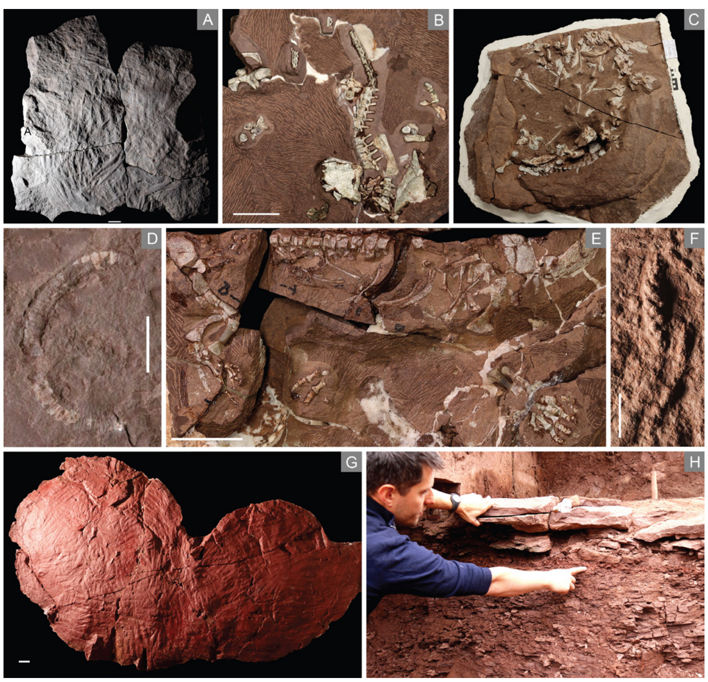

Fig. 10. Excavation highlights. **A**. 2020 excavation. Scratch traces at the bottom of a burrow, "*Megatambichnus*" isp., convex hyporelief. **B**. 2021 excavation. Partly articulated diadectid skeleton. **C**. 2022 excavation. Partly articulated diadectid skeleton in a burrow infill, "*Megatambichnus*" isp. **D**. Excavation 2022, diplopod. **E**. Excavation 2023, *Seymouria sanjuanensis* articulated skeleton, ventral view. **F**. Excavation 2024, plant impression, convex hyporelief. **G**. Excavation 2024, resin cast of scratch traces on the bottom of burrows, in concave epirelief, "*Megatambichnus*" isp. **H**. Excavation 2025, the potential ash layer at the top of BRO II A (LM pointing at it) and a vertebrate burrow at the bottom of BRO I (held by LM). The pictured scale bars are 5 cm (A, B, E, G) and 1 cm long (D, F).

A highlight of the 2022 excavation is the finding of a mostly disarticulated but almost complete diadectid skeleton within a burrow infill of "*Megatambichnus*" isp. (Fig. 10C), found at the transition zone between layer packages BRO II D and E in sectors WE3 and WE4 (Marchetti et al., 2024c). The first bones of this find were already discovered during the dig in 2021 in the EAST sector. Nevertheless, their uncovering had to be stopped in view of only few remaining excavation days because a bone was still stuck in the wall of the WE3 sector where the digging level was much higher than in the neighbouring EAST sector. In 2022, the levelling of both sectors finally allowed the construction of a field jacket (the biggest of the project) around the entire find and its extraction. During this field season, a second smaller jacket was built to extract isolated bones of *Dimetrodon teutonis* found at the transition interval between packages BRO II C and D in sector SN2. This find mainly contains limb bones and is highly relevant for morphological studies of the rare *Dimetrodon* material from the Bromacker locality and for osteohistological analyses. Other highlights include plant remains, specifically seeds which could be determined as *Samaropsis* sp., and diplopod remains (Fig. 10D), both extracted in relatively large numbers during the excavation of 2022.

The most interesting specimen of the field season in 2023 was found on the last excavation day. The field jacket, that was built for extracting this specimen safely, contained an almost complete, articulated skeleton of *Seymouria sanjuanensis* including its skull (Fig. 10E). Additionally, the preparation of this block brought a very small skull of a juvenile temnospondyl to light. An important result of this excavation is the new dig named UE outside the quarry area, that started uncovering the layers above the BRO I sandstone. These new layers mostly consist of laminated mudstone and were named BRO 0 (Fig. 1D). Of special interest are the potential aestivation vertebrate burrows found in this area.

The preparation of the bone finds from 2024 was not finished at the time this paper was drafted. Still, there are already highlights worth being mentioned: The preparation revealed four specimens containing skeleton parts of small tetrapods. All of them were found in layer package BRO II D in sectors SN3 and SN4. Another important find is an articulated diadectid skeleton extracted in two parts within two jackets and found in layer package BRO II D in sector SN5. It is the most articulated diadectid found during the project period. On a sandstone slab of BRO I, scientifically relevant remains of different plant species were discovered (Fig. 10F), among them are several seeds of *Samaropsis* sp. Additionally, raindrops and *Tambia spiralis* are preserved on this slab. For the first time in the project, fossils were casted right in the quarry. To avoid the collection of additional heavy slabs composed of several pieces, three large surfaces with "*Megatambichnus*" scratch traces were casted by using liquid silicon (Fig. 10G). During the lithology excavation in sector UE4, a layer of only few millimetres of thickness was uncovered. Both its composition and its colour are completely different from all other layers that were exposed in the four UE sectors, and might represent a cinerite (Fig. 1D). In view of the dating difficulties concerning the Bromacker locality and the Tambach Formation, this potential cinerite layer would be highly relevant as the containing zircons would probably allow a radiometric dating. Samples of this layer are currently being analysed.

Neither scientific studies nor preparation works on the specimens found during the 2025 excavation were being conducted at the time this paper was drafted. Nevertheless, finds of potential scientific interest can be already named: a lithological excavation was conducted in the northwestern area of the quarry. The focus was on the lithological sequences of BRO I and the directly underlying BRO II A. By excavating and documenting these sequences until the top of BRO II B, the last remaining gap regarding the detailed stratigraphic logs was closed. Findings of special scientific interest in this section are a vertebrate burrow about 10 cm wide and a second potential ash layer (Figs. 1D, 10H). This layer is thicker (ca. 2,5 cm) than the one from UE4, the appearance of the material, however, is very similar to the previously discovered one. It was sampled and will be analysed, too. A small articulated skeleton as well as skull parts of a small tetrapod found in the sector SN14 are further highlights of this excavation. Another important find is a specimen consisting of several elongated, straight bones (likely *Dimetrodon* spines) deposited close to each other and partly overlapping. Few specimens found in the new SN sectors potentially represent Tambia spiralis. This fossil had not been known from the BRO II sequences so far. Moreover, two diplopods and plant material including well-preserved seeds were found in the new sectors.

Scientific relevance of the new excavations

The new excavations between 2020 and 2025 yielded several important scientific results. A large quantity of skeletal material was extracted, including partly articulated diadectids, an articulated *Seymouria*, two disarticulated *Dimetrodon* and several smaller skeletons. This material will be subject to new scientific descriptions, when relevant. Also, the newly found skeletal material includes several long bones that were sampled for osteohistological studies. Furthermore, articulated limbs and autopodia were CT scanned for biomechanical and ichnological studies.

For the first time, a large quantity of well-preserved and diverse vertebrate burrows was discovered, documented and collected (Marchetti et al., 2024b). This includes the first clear evidence of a diadectid within a burrow infill from this locality (Marchetti et al., 2024c) (Fig. 10C). Previous studies only recovered one type of vertebrate burrow so far, which was not formally described (Martens, 2001; Martens et al., 2009). Tetrapod tracks were also found, but in general were scattered finds, although relevant because including ichnotaxa previously unknown from this locality (Marchetti et al., 2023). Moreover, new vertebrate bromalites were found, including the first regurgitalite from this locality (Rebillard et al., 2024).

New invertebrate specimens were found and collected, as well as several conchostracans and rarer blattoid wings and diplopods. As regards invertebrate traces, a large quantity of burrows was discovered and collected, as well as other types of traces previously unknown from this locality. Also, plant material was extracted. Although generally not well-preserved, it yielded information on additional taxa from the site (Luthardt et al., 2024), and this also includes root systems excavated in place.

For the first time, precise GPS coordinates as well as a documentation of each find was implemented in a precise stratigraphic and sector grid. This allows a detailed record of the stratigraphic and areal fossil find distribution within the depositional environment, permitting a reconstruction of the palaeoecosystem in space and time. Moreover, key elements such as preservation, orientation and completeness facilitate an evaluation of the taphonomy of the fossil finds, especially as regards the skeletal material (Buisson, 2024).

For the first time, the entire stratigraphic sequence above the lower sandstone beds named BRO III was excavated (Fig. 1D) and detailed stratigraphic logs were generated. This will allow more detailed stratigraphic and sedimentological studies and a more complete understanding of the locality. Furthermore, two horizons of possible high scientific value were uncovered for the first time. These possible cinerite layers, located near the bases of BRO 0 and BRO I (Figs. 1D, 10H), are now under study in order to understand whether they can provide radiometric ages. These would be extremely important to date the locality and the Tambach Formation, which currently has a minimum age based on biostratigraphy (Menning et al., 2022).

Science Communication in the BROMACKER Project

Objectives and guiding principles

A key objective of the BROMACKER project is to make science more accessible and transparent to the public. Instead of conducting research in isolation, the goal is to create visibility for scientific processes and make them understandable and engaging for a broader audience. The project focuses on communicating the ongoing research questions, results and methodologies at the heart of the work. Importantly, the scientists themselves take on the role of communicators. Their direct involvement permits authentic and enthusiastic engagement with the public: essential for sparking interest in the complex topics at hand. The emphasis is placed on innovative and dialog-based formats that foster a two-way exchange between researchers and civil society. The communication efforts target diverse audiences: curious laypeople, residents and landowners, regional policymakers and early-career scientists. Beyond increasing awareness of the fossil site itself, one of the broader goals is to establish the Bromacker fossil site as a lasting hub for both research and tourism within Thuringia, Germany and beyond. Integration into local tourism networks and tourism infrastructure is therefore an essential component of the communication strategy.

Communication formats and activities

Throughout the excavation period, comprehensive public engagement initiatives were implemented to disseminate research findings and foster broader understanding of Earth sciences. Regular guided tours (Fig. 11), offered in both German and English by researchers and trained guides, were catered to diverse audiences, including the general public, school groups, and VIP visitors. These tours provided insights into various facets of Earth sciences research. In addition to on-site experiences, thematic excursions were organized to scientific drilling locations at Gallberg and Hainfelsen, near the Bromacker site, further enriching the educational outreach. Special family days as a distinct format were designed as full-day events, integrating transportation, catering, and interactive programs. These events uniquely combined a visit to the BROMACKER lab exhibition in Gotha (Fig. 12) with a guided tour of the active excavation site in the Thuringian Forest (approximately 21 km apart). This dual-location approach offered participants a holistic understanding of the Permian world and the ongoing research in that area. To facilitate visitor engagement at the excavation site, a dedicated reception area and a comprehensive signage system were established. Researchers actively participated as visitor care managers, directly engaging with the public. Complementary resources, such as information panels, audio guides and digital links, were provided to enhance the overall visitor experience and deepen their understanding of the scientific work.

A dedicated Instagram channel (#bromacker_chroniken) became the project's primary digital outreach platform. Regular posts shared updates from the field, insights into research processes and live broadcasts from the site. These live sessions facilitated direct dialogue between the scientific team and the online community.

Two major exhibitions were launched as part of the project: the partly interactive BROMACKER lab with hands-on stations in Gotha (Fig. 12) and a complementary exhibit at Schloss Ehrenstein in Ohrdruf. Both present the Permian ecosystem and current research in accessible, engaging ways. The excavation site itself is integrated on the Saurian Discovery Trail, a geo-hiking-trail and part of the UNESCO Global Geopark Thuringia Inselsberg – Drei Gleichen. This thematic hiking route links geologically and paleontologically relevant sites, helping integrate the Bromacker locality into the broader regional

Fig. 11. Guided tours at the Bromacker locality. **A**. The end of a guided tour on the visitor's platform above the quarry during a Bromacker excavation. **B**. A guided tour for a school class in the commercial Bromacker quarry near the excavation quarry.

Fig. 12. The exhibition "BROMACKER lab" in the castle of the Friedenstein Stiftung Gotha. **A**. Thematically structured exhibition stations. **B**. Show preparation on special days like the Long Night of Museums. **C**. The "Tambacher Liebespaar" showing two individuals of *Seymouria sanjuanensis* as one of the original Bromacker fossils exhibited in the BROMACKER lab. Photos courtesy of Lutz Ebhardt (A) and Boris Hajdukovic (B-C).

tourism experience. Regarding the results of this combined approach, some preliminary studies have shown an impact of the BROMACKER project on visitor numbers, which increased from 800 during the 2021 excavation campaign to over 2,000 in 2024 (Alivernini and Reyer-Rohde, 2024). Furthermore, two separate surveys on the awareness of the Bromacker site, conducted among visitors within the Geopark region, recorded a considerable increase from about 10% (Allmrodt, 2011) to values exceeding 50% (Alivernini and Reyer-Rohde, 2023).

Strategic communication and public relations

The excavation periods also marked the peak of strategic communication efforts. Local politicians, media representatives and regional stakeholders were regularly invited to networking events, site tours and press briefings. These face-to-face exchanges reinforced the project's visibility and regional impact. In the run-up to the excavations and drilling, public information events were held to inform and involve the surrounding communities. Press releases and coordinated media outreach supported the excavation phases, and several press trips and on-site broadcasts were conducted in collaboration with regional news outlets. To further integrate the local tourism infrastructure, flyers, posters and event listings were distributed via local tourism information centres and external regional event platforms.

Reflections and challenges

The decision to have researchers actively leading science communication proved to be highly valuable. However, it also generated logistical challenges as communication activities often coincided with intensive excavation work. To manage growing public interest, the project team gradually expanded the guide team to include trained communicators for weekends and peak periods. While time- and resource-intensive, the communication efforts were overwhelmingly considered rewarding. Project members (Fig. 13) described the interactions with visitors as inspiring, appreciative and energising. Ultimately, the outreach work strengthened the public understanding of science and helped to foster a lasting connection between the community and the research undertaking.

Discussion and perspectives

The innovative approach of the BROMACKER project as regards the 2020-2025 excavations at the Bromacker locality had numerous advantages, which are already clearly tangible but will become even more evident in the future years with the publication of the new data. The use of the most modern analytic techniques in a strongly multidisciplinary approach will allow for new thorough studies on aspects not well-investigated previously, such as fossoriality (Marchetti et al., 2024b). The high-resolution stratigraphic logs, not limited to the bone-bearing layers, allowed for a better understanding of the depositional environment at the small scale and permitted the identification of two potential ash layers, that are currently being analysed and might provide for the first time radiometric ages which would finally give an absolute constraint as regards the minimum age of the fossiliferous layers (Menning et al., 2021).

The implementation of a very precise documentation system employing a total station is a substantial step forward compared to previous excavations, from which the data of the fossil finds and stratigraphy are unprecise, scattered, uncertain or non-existing (e.g., Eberth et al., 2000). The clear documentation of each finding and of relevant stratigraphic intervals allows for a clear reconstruction of the depositional environment, taphonomy and palaeoecology of the site (e.g., Buisson, 2024), which previously lacked detail, which is however necessary in the case of densely fossiliferous levels and varying facies such as those of the Bromacker fossil lagerstätte. This documentation system also had clear advantages from the perspective of specimen collection, storage, preparation. In fact, extensive data on the collected specimens allow for a readily cataloguing of the specimens and a sure reconstruction of the original multi-piece specimens, which was seldom the case in previously collected material.

Fig. 13. The excavation team in 2021 in the northwestern area of the quarry.

The integration of several science communication activities to the excavations, tried for the first time for this locality, brought astonishing results especially as regards the increased frequentation of the site and the overall positive experience for both the visitors and the excavation staff. So, for the future of the Bromacker fossil lagerstätte it is important to make treasure of this experience and to promote a combined interaction of science and science communication during the excavations, which can help not only the development of science, collections and exhibitions but also the local tourism in a virtuous circle.

Acknowledgements

This work has been funded by the Bundesministerium für Bildung und Forschung (BMBF) for the project “Opening science: new ways of knowledge transfer using the example of the BROMACKER research project”, grant number 01UO2002A.

Author contributions

LM and SK contributed equally to the manuscript. LM wrote “Stratigraphy and fossil content”, “Excavation results” and “Discussion and perspectives”; SK wrote “Introduction”, “Excavation methods” and “Excavation results”. SB and MA wrote “Science communication in the BROMACKER project”. SK and LM made all the figures. All the authors revised the manuscript.

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Mid-Artinskian (early Leonardian) fusulinids and conodonts from the upper part of the "Wolfcamp Shale" in Crockett County, Texas, with subsurface correlations from the Midland Basin

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Preface

Depending on geologic context and, to some extent, professional experience (i.e., academic vs. industry), the Wolfcamp/Wolfcampian name is subject to multiple interpretations and uses. In the North American chronostratigraphic framework, Wolfcamp/Wolfcampian refers to either: 1) the lower regional stage of the Cisuralian Series, with which it shares a lower boundary; 2) the lower part of the Cisuralian and the uppermost part of the Upper Pennsylvanian Series (i.e., "Newwellian"), with a mid-Gzhelian lower boundary. However, professionals in the petroleum industry might be more familiar with the so-called "Wolfcamp Shale," an informally recognized subsurface lithostratigraphic unit of the Midland and Delaware basins comprising strata of Kasimovian through lower Kungurian age. This subsurface "Wolfcamp Shale" is distinct from surface exposures of the type "Wolfcamp Formation," which crop out in the Glass Mountains near Marathon, Texas. For the sake of brevity and to avoid getting lost in the weeds, I refer interested readers to Lucas and Shen (2018) and Camp (2025)

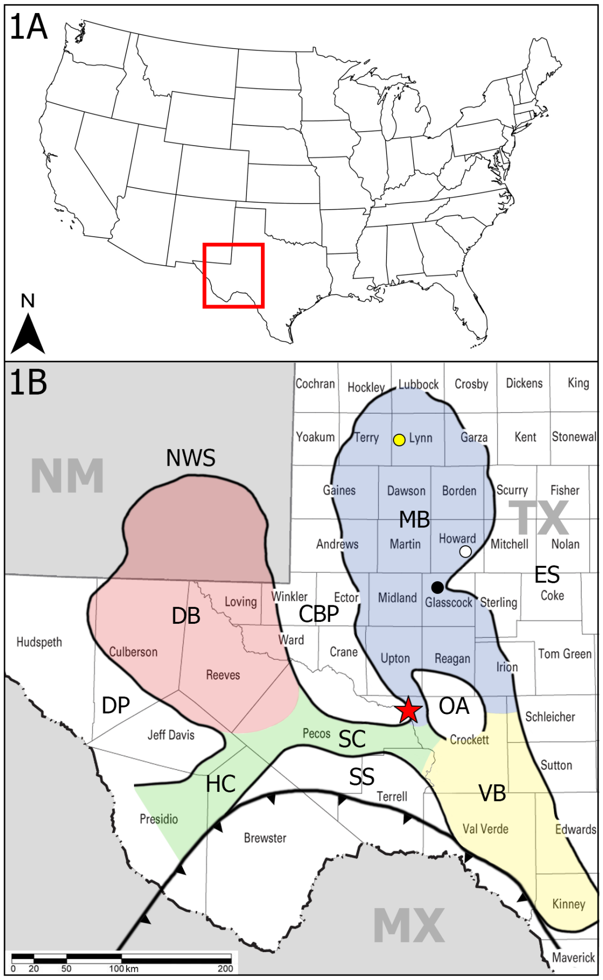

Fig. 1. **A**. Index map of the Permian Basin in West Texas and southeastern New Mexico, USA; **B**. Map of the Permian Basin illustrating significant paleogeographic features with country, state, and Texas county borders: TX – Texas; NM – New Mexico; MX – Mexico; Pink – Delaware Basin (DB); green – Hovey Channel (HC) and Sheffield Channel (SC); blue – Midland Basin (MB); yellow – Val Verde Basin (VB); Diablo Platform (DB); Northwestern Shelf (NWS); Central Basin Platform (CBP); Southern Shelf (SS); Ozona Arch (OA); Eastern Shelf (ES). The red star denotes the Simpson Canyon 4045 Unit #1 wellsite, the black circle denotes the Pan American #1 E.L. Powell wellsite, the white circle denotes the Lario O & G #2 Barber wellsite, and the yellow circle denotes the Shell Stephens L1V wellsite. The southern orogenic front is the Marathon-Ouachita fold and thrust belt.

for useful summaries concerning the history of the polysemous "Wolfcamp" name.

Introduction

The "Wolfcamp Shale" is an organic-rich accumulation of slope and intracratonic basinal sediments recording the infilling of the rapidly subsiding Permian Basin system (Mazzullo, 1997). Since the first major West Texas petroleum discovery in 1923, the greater Permian Basin region has become synonymous with prolific petroleum reserves, producing an estimated 30+ billion barrels of oil over the past century (Wiseman, 2023). Following a decline in production after peaking in 1973, interest from the petroleum industry was reignited in the late 1990s and early 2000s with the broader implementation of hydraulic fracturing and horizontal drilling in "tight" oil and gas plays -- such as the "Wolfcamp Shale." In the Midland Basin, the "Wolfcamp Shale" is the principal target for hydraulic fracturing operations, with the majority of modern production coming from the upper part of the unit. However, considerable economic and geologic interest notwithstanding, the biostratigraphy and chronostratigraphy of the "Wolfcamp Shale" is often overlooked. With the notable exceptions of work by Jim Barrick (Professor Emeritus, Texas Tech University), Greg Wahlman (Amoco, BP) and the late Garner Wilde (Humble, Exxon, Harper Oil), only a handful of micropaleontologists have conducted significant research on the late Paleozoic microfaunas of the subsurface Midland Basin.

The present study introduces additional biostratigraphic control for the upper part of the "Wolfcamp Shale" by integrating mid-Artinskian fusulinid and conodont occurrences from a core of the Simpson Canyon 4045 Unit #1 well in Crockett County, Texas. The Simpson Canyon 4045 Unit #1 core has been included in the materials of two Master's theses concerned with the petrology and chemostratigraphy of the upper "Wolfcamp Shale" (Turner, 2016; Blizzard, 2020), but this is the first report on the biostratigraphy of the core. The 121' (37 m) core was recovered from one of the southernmost "Wolfberry" fields (Wolfcamp + Spraberry) in the Midland Basin and offers multifaceted correlation potential to help fill regional data gaps and, perhaps more importantly, provides further clarity on the placement of the Wolfcampian-Leonardian boundary within the International Permian Timescale.

Geologic setting and stratigraphy

The Simpson Canyon 4045 Unit # 1 wellsite is located in northwestern Crockett County, Texas, approximately 4 km north of the town of Iraan (pronounced "eye-ruh-ann"). The upper part of the "Wolfcamp Shale" at this locality was deposited in a slope setting along the southeastern margin of the Central Basin Platform (CBP), a NNW-SSE-trending composite block of upthrown Precambrian basement rock separating the Delaware Basin (to the west) from the shallower Midland Basin (to the east) (Shumaker, 1992) (Fig. 1). The adjacent Ozona Arch was possibly a forebulge feature of the Val Verde Basin to the southeast (Fairhurst et al., 2021). Uplift of the CBP was likely induced in tandem by Ouachita orogenesis and the development of the Ancestral Rockies during the Carboniferous, and significant movement ceased during the early Cisuralian (Shumaker, 1992; Hoak et al., 1998; Horne et al., 2024). Displacement possibly occurred along reactivated faults associated with Proterozoic and Cambrian rifting events (Horne et al., 2024). The Midland Basin was located at low paleolatitudes between 2 and 10 degrees north of the equator, and carbonate accumulation capped the CBP throughout much of the Cisuralian (Golonka, 1991; Walker et al., 1992; Hoak et al., 1998). Slope deposits of the CBP-Midland Basin transition mostly consist of fine-grained, hemipelagic siliciclastic sediments, argillaceous limestone, and allochthonous carbonate material transported from the shelf margin by gravity flows (Hobson et al., 1985; Turner, 2016, unpublished MS thesis). Allochthonous slope carbonates range in composition from discrete grains homogeneously mixed with siliciclastic "background" sediments to reworked limestone clasts of pebble to cobble size.

The "Wolfcamp Shale" varies in thickness from approximately 245 m to more than 2200 m in the central Delaware Basin (avg. 550 m) and is subdivided into four informal members, or "benches," known as Wolfcamp D, C, B, and A (ascending) (Camp, 2025) (Fig. 2). These subdivisions, which are most commonly used in the petroleum industry, are distinct lithofacies packages identified from cores, cuttings, and borehole logs from several thousand wells in the region. Wolfcamp D, also known as the "Cline Shale," is Kasimovian to mid-Gzhelian, Wolfcamp C is mid-Gzhelian to mid-Sakmarian, Wolfcamp B is mid-Sakmarian to mid-Artinskian, and Wolfcamp A is mid-Artinskian to approximately the Artinskian-Kungurian boundary (Henderson and Read, 2023). In the Midland Basin, the "Wolfcamp Shale" disconformably overlies Middle Pennsylvanian strata of the Strawn Group (sometimes assigned formation rank; Moscovian) and is conformably overlain by the Dean Formation (lower Kungurian).

The Simpson Canyon 4045 Unit #1 well penetrates the entirety of Wolfcamp A and the total depth of 6300' (1920 m) likely places the bottom of the well in the lower part of Wolfcamp B, based on local thickness maps. The Wolfcamp B-Wolfcamp A contact is at a depth of ~5919' (1804.3 m) and is denoted by the base of a "hot shale"-dominated interval (Hamlin and Baumgardner, 2012; Baumgardner et al., 2016; Wahlman et al., 2016). Jeary (1978) and Mazzullo et al. (1987) referred to the shale interval as the "Wolfcamp Shale Marker" (WSM) and suggested the top of this "regionally persistent black shale section" approximates the Wolfcampian-Leonardian boundary, with the *Schwagerina crassitectoria* Zone (lower Leonardian) occurring above the WSM and late Wolfcampian fusulinids occurring below. Although slope settings, like those discussed herein, record dynamic and locally episodic sedimentation events, the WSM does seem to exhibit significant lateral continuity and is apparently correlative with the shale unit below the "third Bone Spring Sandstone" in the northern Delaware Basin (Mazzullo et al., 1987). Mazzullo et al. (1987) suggested the WSM interval is a record of regional subsidence nearly coeval with the Wolfcampian-Leonardian boundary. Simpson Canyon 4045 Unit #1 was cored from 5876' (1791 m) down to 5997' (1828 m). The lower portion is composed of heterogeneous, carbonate orthoconglomerate debris flow deposits (i.e., limestone debrites) that grade upward into finer-grained, bioclastic argillite-to-argillaceous limestone with minor black shale drapes in the middle segment of the core. The upper portion is dominated by less bioclastic, organic-rich argillite and the black shale that characterizes the WSM interval (Fig. 3).

Fusulinid biostratigraphy

Three 25 cm intervals of the Simpson Canyon 4045 Unit #1 core were sampled for fusulinids from depths of 5922' (1805 m), 5911' (1801.7 m), and 5894' (1796.5 m). The lower portion

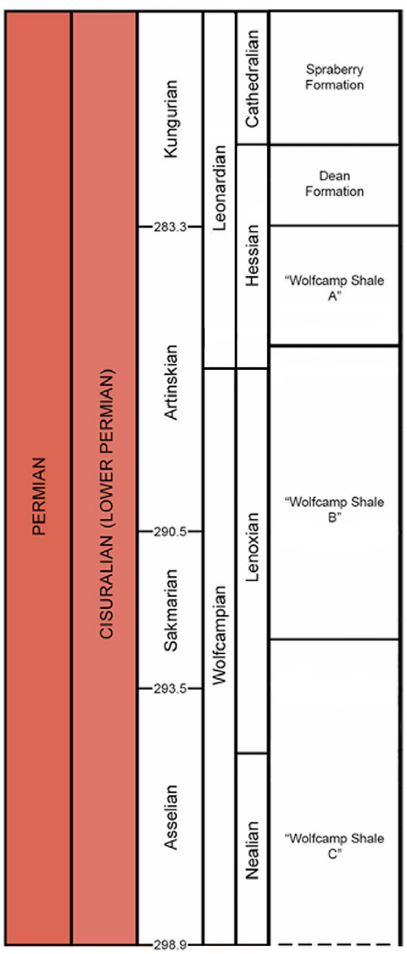

Fig. 2. Cisuralian stratigraphy of the Midland Basin, West Texas (modified from Henderson and Read, 2023).

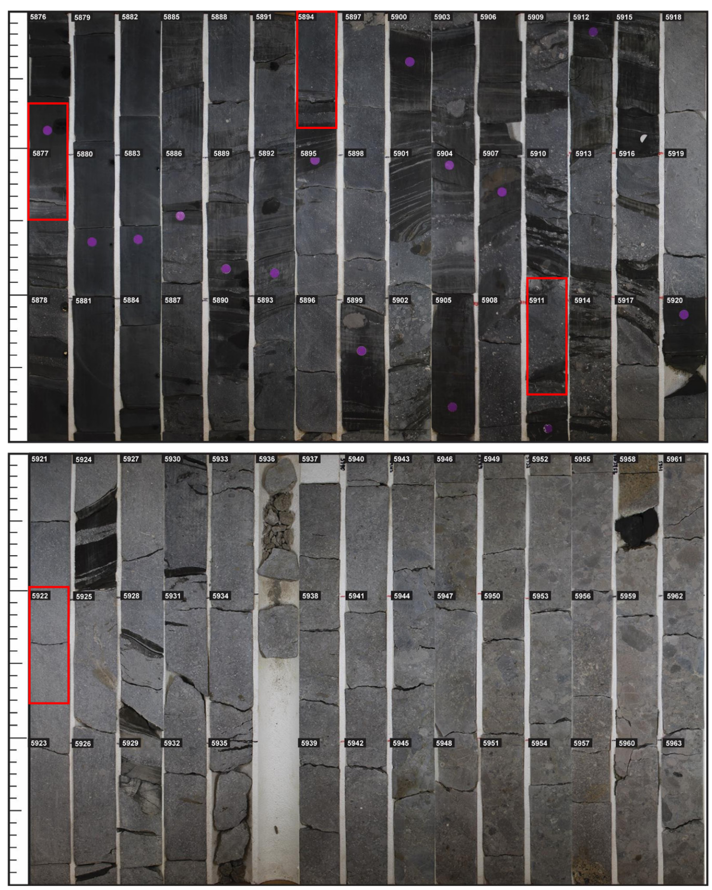

Fig. 3. Photographs of the cored interval (slabbed side) from Simpson Canyon 4045 Unit #1 (in part) with red boxes around sampled segments (modified from Turner, 2016, unpublished MS thesis). Purple stickers are from a previous study.

of the core was not sampled due to the significant heterogeneity of the coarser debris flow unit. Although Mazzullo et al. (1987) and others have suggested the WSM is equivalent to the Wolfcampian-Leonardian boundary, both the present study and the work of Wahlman et al. (2016) indicate the uppermost part of Wolfcamp B is Leonardian. Well-preserved fusulinids recovered from the cored interval of the Simpson Canyon 4045 Unit #1 well include *Schwagerina hawkinsi* Dunbar and Skinner (5922'/1805 m), *Schwagerina hessensis* Dunbar and Skinner (5922'/1805 m), *Skinnerella schucherti* (Dunbar and Skinner) (5922'/1805 m), *Skinnerella biconica* Skinner (5911'/1801.7 m), and *Parafusulina allisonensis* Ross (5894'/1796.5 m) (Fig. 4). All five fusulinid taxa were described from mid-Artinskian (lower Leonardian) shelf successions of the Diablo Platform or the Southern Shelf (i.e., Glass Mountains). Several of these species are also known to occur in eastern Nevada, in or near the Pequop Mountains and the Rockland section, which includes a continuous Artinskian carbonate succession and the current Kungurian GSSP candidate.

The lowermost collection from the core (5922'/1805 m) has the greatest abundance and diversity of fusulinids among the three sampled intervals. In the Glass Mountains, *Schwagerina hawkinsi* and *Schwagerina hessensis* are known to occur in shelf lithofacies of the lower part of the Hess Limestone, the equivalent slope lithofacies of the Decie Ranch Member of the Skinner Ranch Formation (Dunbar and Skinner, 1937; Ross and Ross, 2003; Wahlman, 2019). In the Hueco Mountains, both species also occur in the upper member of the Alacran Mountain Formation (Dunbar and Skinner, 1937). Additional occurrences of these taxa outside the Permian Basin include collections from the Pequop and Garden Valley formations of the Pequop and Diamond mountains (respectively) in eastern Nevada (Robinson, 1961; Bissell, 1962). *Skinnerella schucherti* was described from the lower part of the Bone Spring Formation in the Sierra Diablo (Dunbar and Skinner, 1937), and it has also been reported from eastern Nevada, where it occurs in the Pequop Formation of the southern Egan Range, near Ely, Nevada (Langenheim et al., 1960). *Skinnerella biconica*, which was recovered from the Simpson Canyon core at 5911' (1801.7 m), was originally described from the lower part of the Bone Spring Formation in the Baylor Mountains (Skinner, 1970). The uppermost taxon recovered from the core is a single specimen of *Parafusulina* cf. *allisonensis* (5894'/1796.5 m), yet another typical Glass Mountains species. *Parafusulina allisonensis* is one of the earliest species of true *Parafusulina* (excluding related taxa, like *Skinnerella*). Whereas the taxa occurring lower in the cored interval are characteristic of the *Schwagerina crassitectoria* Zone, *P. allisonensis* is a typical component of the lower part of the overlying "transitional *Parafusulina* Zone" of Wilde (1990), suggesting it might range from middle-to-upper Artinskian into the lower Kungurian (Wilde, 1990). In eastern Nevada, *P. allisonensis* has been reported from the uppermost Ferguson Mountain Formation at the unit's type locality, where it reportedly co-occurs with *Sk. schucherti* and *Sch. hessensis* (Bissell, 1962).

Conodont biostratigraphy

The same three segments of core were processed for conodont elements, with an additional sample from the top of the core at 5977' (1821.8 m) that yielded neither conodonts nor fusulinids. The argillaceous nature of the Simpson Canyon 4045 Unit #1 core presents a challenge in processing samples for conodont elements. Much of the bioclastic portion of the core contains a minor amount of calcareous matrix and cement, thus inhibiting formic acid digestion and resulting in only partial disaggregation of sample material. Alternative methods for fine-grained siliciclastic materials will be used to attempt further extraction in the coming months. Despite the difficulty, a few complete P1 elements were recently recovered from insoluble residues, including *Hindeodus* sp. (5922'/1805 m), *Mesogondolella bisselli*

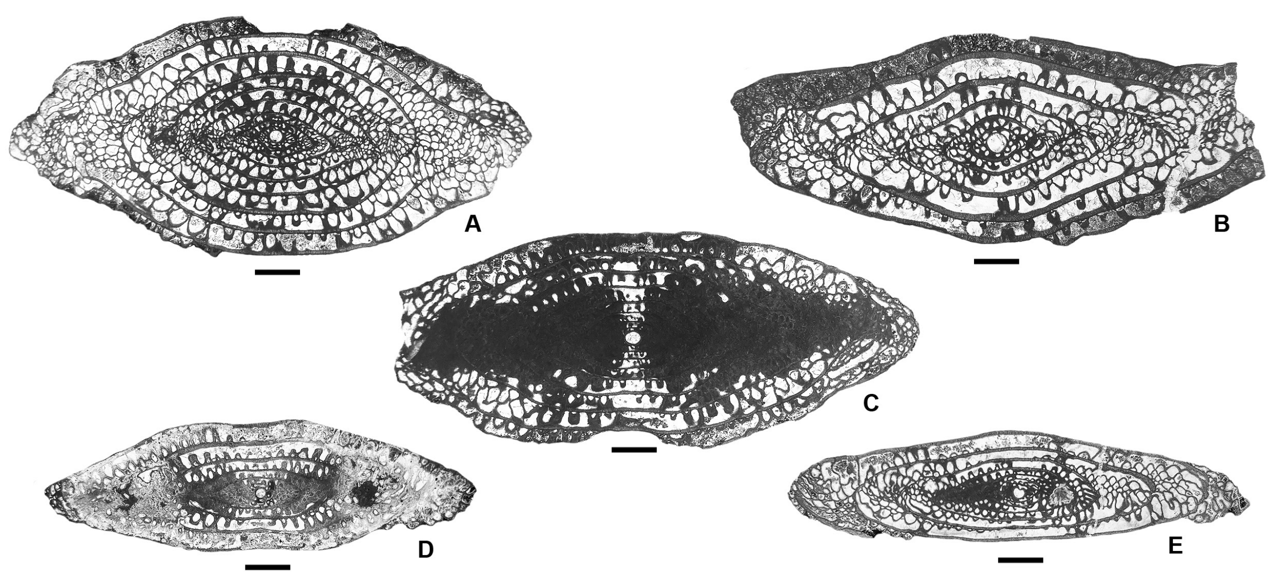

Fig. 4. Fusulinids from the Simpson Canyon 4045 Unit #1 well, Crockett County, TX; **A**. *Schwagerina hawkinsi* (5922'/1805 m); **B**. *Schwagerina hessensis* (5922'/1805 m); **C**. *Skinnerella schucherti* (5922'/1805 m); **D**. *Skinnerella biconica* (5911'/1801.7 m); **E**. *Parafusulina* cf. *allisonensis* (5894'/1796.5 m). Scale bars = 1 mm.

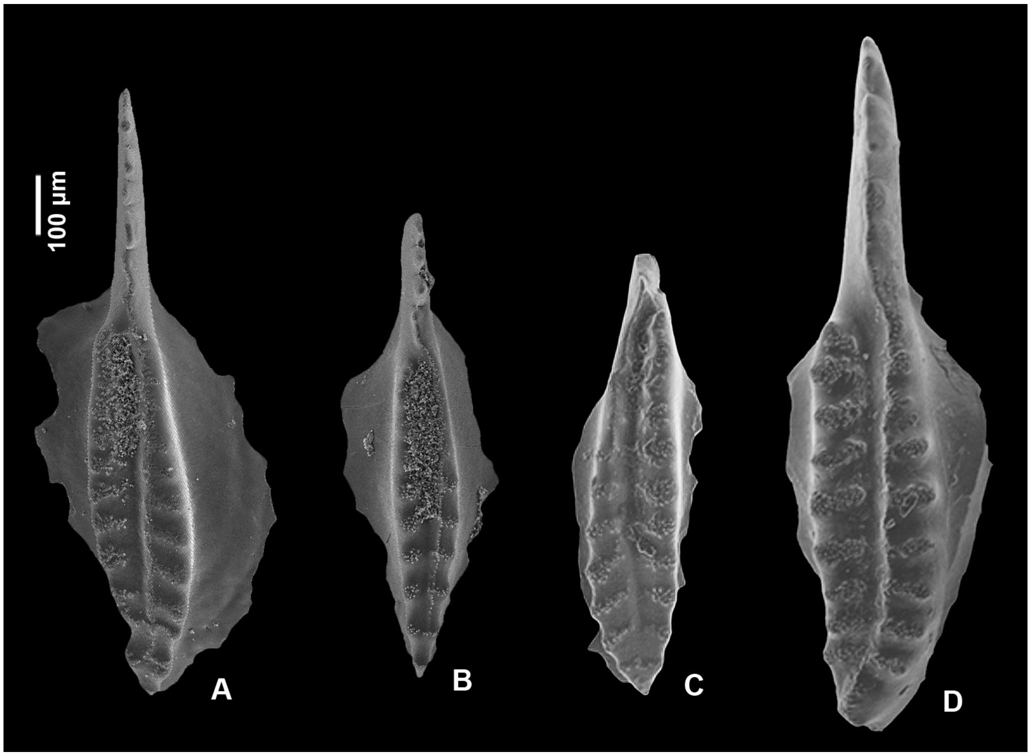

Fig. 5. Conodonts from the Simpson Canyon 4045 Unit #1 well and the Shell Stephens L1V well of Kohn et al. (2019) (for comparison); **A**. *Sweetognathus* ex gr. *clarki*; **B**. *Sweetognathus* ex gr. *clarki*; **C**. "*Neostreptognathodus ruzhencevi*" from Kohn et al. (2019); **D**. "*Neostreptognathodus ruzhencevi*" from Kohn et al. (2019).

(Clark and Behnken) (5922'/1805 m), and *Sweetognathus* ex gr. *clarki* (Kozur in Kozur and Mostler) (5911'/1801.7 m). The latter is the most informative taxon of the conodont assemblage and provides additional correlation potential for the upper portion of the Simpson Canyon 4045 Unit #1 core (Fig. 5). Although the Simpson Canyon specimens differ somewhat from typical *Sw. clarki* in their carinal configuration, this stage of sweetognathid advancement (i.e., transitional *Sweetognathus-Neostreptognathodus*) is diagnostic of the mid-Artinskian.

Correlations across the Midland Basin

Biostratigraphic correlations herein are concerned with two previous studies of the "Wolfcamp Shale" in the Midland Basin by Wahlman et al. (2016) and Kohn et al. (2019). Wahlman (2016) presented a detailed study of Kasimovian-Artinskian (Missourian-early Leonardian) fusulinid occurrences from 15 "Wolfcamp Shale" wells in the eastern Midland Basin and Eastern Shelf. Several other cores lacking fusulinid samples were included to incorporate conodont data. Correlations of the Simpson Canyon 4045 Unit #1 core with two of the cores from Wahlman et al. (2016) were interpreted on the basis of well log signatures and fusulinid occurrences (Fig. 6). The datum on which the three logs are hung is the base of the WSM interval, identified by an abrupt decrease in the gamma ray response and the onset of "hot shale" accumulation. From the Pan American #1 E.L. Powell well, in Glasscock County, Wahlman et al. (2016) recovered *Schwagerina hessensis* and *Schwagerina crassitectoria* Dunbar and Skinner from a peloidal-bioclastic packstone interval at depths of 8132 to 8106' (2478.6-2470.7 m). The overlying succession of debris flow deposits, from 8106 to 8050' (2470.7-2453.6 m), yielded *Skinnerella biconica* and *Skinnerella* aff. *schucherti*, and the WSM base occurs at a depth of approximately 8090' (~2465 m) (Wahlman et al., 2016). The second reference well is Lario O & G #2 Barber, located in central Howard County. The basal WSM depth here is approximately 6000' (~1828 m), and Wahlman et al. (2016) reported *Sch. hawkinsi*, *Schwagerina dugoutensis* Ross, and *Parafusulina* aff. *allisonensis* from a skeletal packstone-to-grainstone at depths of 5991 to 5930' (1826-1807.5 m). The presence of several shared index taxa near the Wolfcamp B–Wolfcamp A transition (i.e., the WSM datum) allows for strong correlation among the three cores, despite the wellsites being located on opposing slopes of the southwest and east-central Midland Basin (Fig. 1).

The third reference well of interest is Shell Stephens L1V, located in west-central Lynn County, in the northern Midland Basin. No log correlation with the Shell Stephens L1V well is included in Figure 6, as the WSM is not as prominent as it is on the three logs illustrated. Although no fusulinids have been reported from the Shell Stephens L1V well (to the author's knowledge), Kohn et al. (2019) provided conodont biostratigraphy for three cored intervals from Wolfcamp D-Wolfcamp C2 (= lower Wolfcamp C), Wolfcamp C1 (= upper Wolfcamp C), and Wolfcamp B-Wolfcamp A. The uppermost core yielded P1 elements of *Mesogondolella bisselli*, *Sweetognathus asymmetricus* Sun and Lai in Sun et al., *Neostreptognathodus exsculptus* Igo, and a form the authors identified as *Neostreptognathodus ruzhencevi* Kozur in Kozur and Mostler (Kohn et al., 2019). The latter taxon was used to approximate the Wolfcampian-Leonardian boundary and is nearly identical to the few specimens recovered from 5911' (1801.7 m) in the Simpson Canyon core, reported herein as *Sweetognathus* ex gr. *clarki*. This assignment is preferred to *N. ruzhencevi* due to the more asymmetrical carina and presence of a lateral pustulose ridge on the "Wolfcamp Shale" forms. Given the current consensus that *Sw. clarki* is an evolutionary descendant of *Sw. asymmetricus*, the offset position of the pustulose ridge seems logical, as the medial ridge and transverse nodes of *Sw. asymmetricus* would have potentially given way to a laterally displaced pustulose ridge during sulcus development in *Sw. clarki*. Interestingly, this specific morphotype does not seem to have been found elsewhere outside the Midland Basin and differs from the types of both *N. ruzhencevi* and *Sw. clarki*, thus the present use of open nomenclature with *Sw.* ex gr. *clarki.* In any case, these sweetognathid taxa are coeval with one another and Mei et al. (2002) regarded *N. ruzhencevi* as a junior synonym of *Sw. clarki* - the nominate zonal taxon for the middle part of the Artinskian (Henderson, 2018).

Conclusions

The base of the Wolfcamp A unit, the uppermost informal member of the "Wolfcamp Shale," has been used to approximate the Wolfcampian-Leonardian boundary (mid-Artinskian) since the late 1970s, but more robust biostratigraphic control for this interval has only come about in the past 15 years or so. Consequently, a more comprehensive chronostratigraphic understanding of the upper part of the "Wolfcamp Shale" is still developing. In reality, the Wolfcampian-Leonardian boundary is in the upper part of Wolfcamp B, as discussed by Wahlman et al. (2016). The recovered microfaunas of the Simpson Canyon 4045 Unit #1 core allow for subsurface correlations of the Wolfcamp B-Wolfcamp A transition to be extended to the southernmost part of the Midland Basin. Combining well logs with the occurrences of key index taxa in the upper portion of the core facilitates precise correlation with several biostratigraphically constrained reference wells from the eastern and northern Midland Basin. Additionally, the fusulinid assemblage in particular can be tied to the classical type areas of the "Wolfcamp Formation" in the Glass Mountains, where surface exposures record age-equivalent carbonate platform deposition.

Acknowledgment

The author thanks Dr. Julie Bloxson of SFASU and the East Texas Core Repository for allowing sampling of the Simpson Canyon 4045 Unit #1 core.

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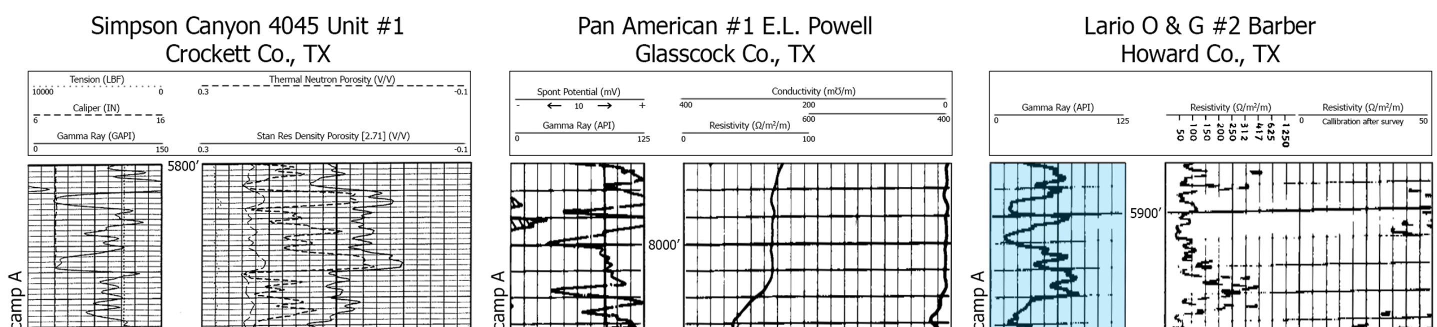

Fig. 6. Partial well logs from three Midland Basin boreholes through the "Wolfcamp Shale." Simpson Canyon 4045 Unit #1 is the focus of this study and Pan American #1 E.L. Powell and Lario O & G #2 Barber are reference wells. Logs are hung on the basal "Wolfcamp Shale Marker" (WSM) datum (red line). Blue shading highlights the cored intervals of each well. Fusulinid occurrences from the Simpson Canyon 4045 Unit #1 core are indicated by black ovals to the right of the gamma ray curve and conodont occurrences are denoted by black stars.

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The genus *Nuskoisporites* revisited: new information on its stratigraphic and paleogeographic range

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The genus *Nuskoisporites* includes large monosaccate pollen with a trilete mark, with *Nuskoisporites dulhuntyi* Potonié et Klaus designated as the type species. This genus is associated with male cones of the conifer *Ortiseia* Florin (Walchiaceae) (Clement-Westerhof, 1984; Kustatscher et al., 2024). Since its definition in 1954, *Nuskoisporites* has been widely used as a biostratigraphic marker of the Lopingian of Europe. However, the genus underwent numerous revisions due to many taxonomic changes, including emendations and the inclusion of new species, which were later reassigned to other genera or synonymized. A notable revision was made by Poort et al. (1997), which established the distribution of *Nuskoisporites* for the Lopingian of the Euramerican phytoprovince, specifically the European part. Nevertheless, recent confirmed records of *Nuskoisporites* in older strata (Kustatscher et al., 2024) have reopened the debate requiring an updated revision. Our recent publication in the "*Review of Palaeobotany and Palynology*" detailed a comprehensive review of all previous occurrences of *Nuskoisporites*, along with a morphometric analysis of new materials from various regions and time intervals (Barreiro et al., 2025). This enabled the differentiation of two distinct morphotypes within the genus, thereby facilitating a refinement of the chronostratigraphic and paleogeographic distribution of *Nuskoisporites*.

Nuskoisporites: Two morphotypes

The morphometric analysis was based on three variables: total pollen diameter, total size to central body ratio (P:CB), and central body to laesurae (each of the three "arms" of the trilete mark) length ratio (CB:L). While the existence of disparities between the older and younger specimens had been suspected, the Principal Component Analysis (PCA) confirmed this hypothesis, demonstrating that the specimens could be categorized into two distinct populations according to their age interval, Cisuralian and Guadalupian-Lopingian. Even though all the specimens conformed to the original description of *Nuskoisporites*, two distinct morphotypes were identified (Fig. 1). Morphotype 1 exhibited a total pollen size range of 90–150 µm (average ~110 µm), a higher CB:L (~0,3), and a thicker but diffuse limbus. Morphotype 2 showed a total pollen size ranging 100–300 µm (average ~160 µm), a lower CB:L (~0,1–0,2), and a thinner but well-defined limbus.

After the revision of Poort et al. (1997), only one species was incorporated into *Nuskoisporites*, namely *N. dulhuntyi*. Do the results of this study indicate the presence of two distinct species? We still don't know. Further research is necessary, particularly with respect to the presumed older morphotype.

Updated chronostratigraphic and paleogeographic distribution

Whether morphotypes 1 and 2 are the same species (*N. dulhuntyi*) or not, our results have biostratigraphic implications since both have distinct and well-defined stratigraphic ranges (Fig. 1). The older records are associated with Morphotype 1. The first occurrence has been identified in the Moscovian of the Ghadamés Basin, Libya (Massa et al., 1980; Coquel et al., 1988). New reported occurrences have been documented in the Asselian of the Sudetes (Poland) and the lower Sakmarian of the Lodève Basin (France) (Barreiro et al., 2025). A record has been identified in the Tim Mersoï Basin, Niger, which is presumed to be assigned to the Kungurian–Roadian interval (Broutin et al., 1990). Unfortunately, unlike previous records, the latter lacks independent age control. The "typical" Lopingian *Nuskoisporites* corresponds to Morphotype 2, which also includes Guadalupian and even uppermost Cisuralian records. The first occurrence of this morphotype is documented in the upper Kungurian of the Athesian Volcanic District, Italy (Kustatscher et al., 2024; Spina et al., 2025). However, there is no evidence of its survival beyond the Permian–Triassic boundary. All the post-Permian records are clearly interpreted as reworked.

In terms of the paleogeographic distribution, both morphotypes exhibit a broad distribution, reaching multiple phytoprovinces (Euramerica, Gondwana, and sporadically Angara and Cathaysia) and a wide latitudinal range. However, during the Lopingian, a geographic contraction was observed, with records restricted to

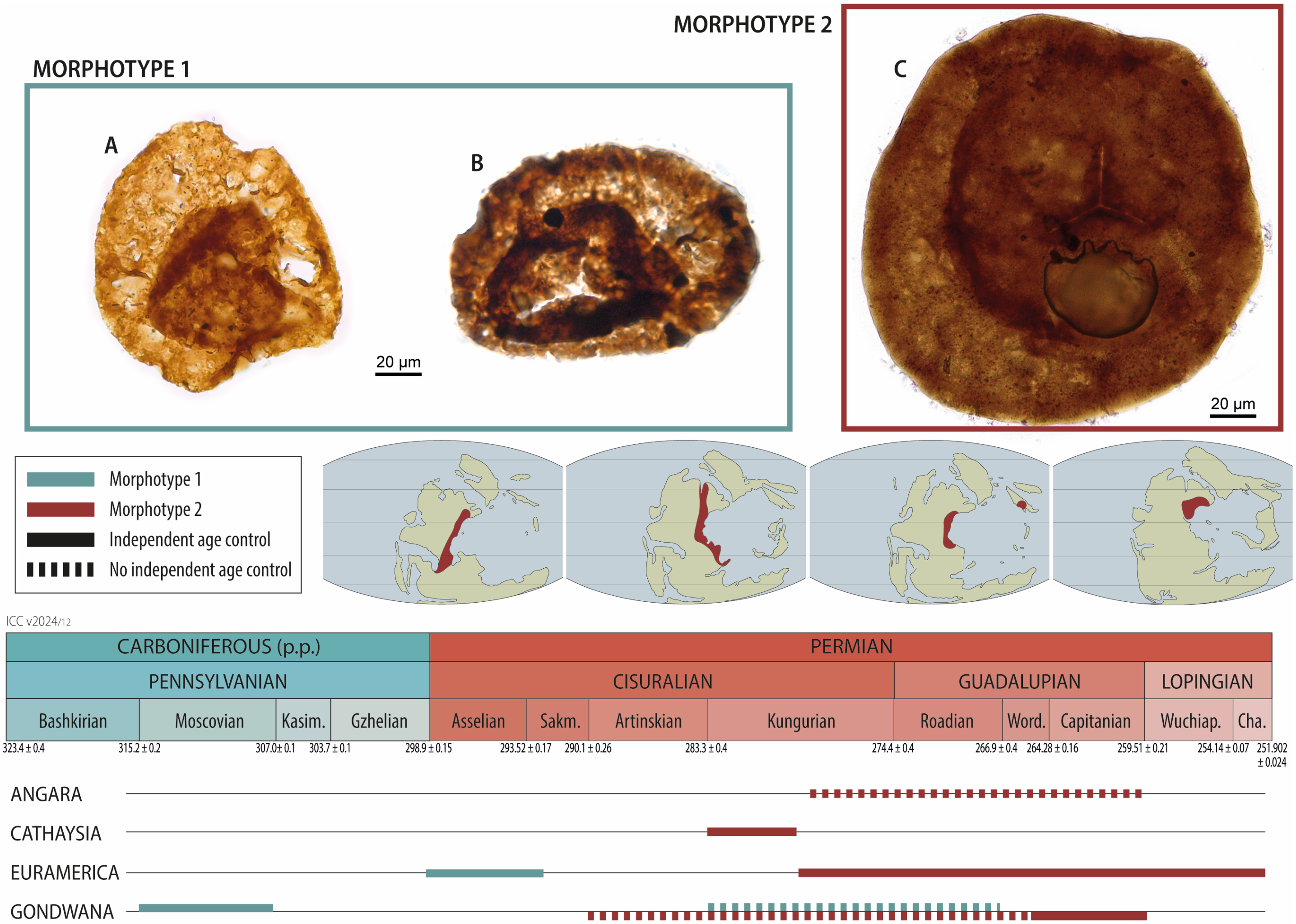

Fig. 1. Examples of Nuskoisporites' morphotypes and its chronostratigraphic distribution within each phytoprovince. A. Morphotype 1 (Lodève Basin, France), B. Morphotype 1 (Sudetes, Poland), C. Morphotype 2 (Val Gardena Formation, Italy). Same scale for all the specimens. Figure modified from figures 3 and 8 in Barreiro et al. (2025).

low latitudes on the western Tethyan coast (Euramerica p.p.). This decline aligns temporally with an intensification of global aridification and recurring episodes of environmental stress, leading up to the end-Permian crisis (Sun et al., 2012; Retallack, 2013).

Conclusions

The thorough revision of previous and new records of *Nuskoisporites* enabled us to 1) recognize two morphotypes with different temporal ranges, 2) expand and refine the chronostratigraphic and paleogeographic ranges previously accepted for the genus, and 3) link the disappearance of this genus and its producer plant to the ecological stress episodes culminating in the end-Permian crisis.

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Further contributions towards the re-evaluation of Indian Late Paleozoic spores and pollen to resolve gaps in global correlation

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Pervading taxonomic biases in the Permian sequences are hampering global correlation, as pointed out by Modie and Le Hérissé (2009), Barbolini et al (2014), among others. Therefore, resolving taxonomic discrepancies persisting among Permian palynological basins is one of the many objectives of the Gondwana to Euramerica correlations Working Group. This facilitates refining intercontinental biostratigraphic correlation. Therefore, in continuation with our efforts to resolve the taxonomic discrepancies persisting between those described from Indian Gondwana basins and their coeval Permian counterparts, we have results on the genus *Parasaccites* Bharadwaj and Tiwari 1964, long debated across Gondwana as conspecific to *Cannannoropollis* Potonié and Sah 1960 but still in usage in India.

Cannanoropollis Potonié and Sah 1960 is a Late Paleozoic morphogenus of cordaitalean affinity instituted for circular to subtriangular radial trilete monosaccate pollen grains, with an irregularly notched velum with radial folds and a distinct to indistinct trilete mark, retrieved from the Tertiary lignites of Cannanore Beach of Malabar coast in the State of Kerala, Southern India. Later in 1964, Bharadwaj and Tiwari erected a new morphogenus, *Parasaccites*, for circular to bilaterally oval, radial monosaccate pollen grains with proximal and distal subequatorial zones of saccus attachment to the central body, from the early Cisuralian sediments of Korba coalfield, Son-Mahanadi Basin, central India.

Foster (1975, 1979) re-examined the photomicrographs of the type materials, *C. janakii* Potonié and Sah 1960 and P. korbaensis Bharadwaj and Tiwari 1964, and found no apparent differences between them.

Therefore, to resolve this discrepancy and re-affirm if *Parasaccites* merits a generic status or not, or should be considered as junior synonym of *Cannanoropollis* as claimed, we carried out an extensive review of the older systematic works, and re-examined illustrated specimens and slides of available holotypes/paratypes of both genera under transmitted light microscope, confocal laser scanning microscope and scanning electron microscope. They were also compared with palynological material collected from the Damodar Basin (East India) and the Wardha Basin (Central India) and from South American basins (Bolivia, Argentina, Brazil, and Uruguay). They were analysed at every stage of acid treatment to observe their effect on the morphology of the grains. The morphological features re-examined are amb, corpus, nature of saccus, and diameter, all of which revealed no apparent differences between the two genera. Although the nature of the zone of attachment, which was the main distinguishing character, is difficult to determine based on the preservation of the specimens, it was not mentioned in the original diagnosis of *Canannoropollis*. Later works mentioned this feature (Foster 1979, Azcuy and di Pasquo 2000) and was observed in our present study, wherein well-preserved specimens displayed different zones of saccus attachment ranging from subequatorial proximal and distal attachment, to proximally equatorial–subequatorial to distally subequatorial attachment. Therefore, we propose to amend the diagnosis of *Cannanoropollis* to incorporate possible attachment zones.

The rest of the features of *Parasaccites* overlap with *Canannoropollis* and therefore do not warrant a generic status for *Parasaccites*. Thus, this work reaffirms that *Parasaccites* is a junior synonym of *Canannoropollis*, and by the nomenclatural rule of priority, its further usage is to be avoided. A critical re-analysis of the available holotypes of the species of *Parasaccites* from India carried out in the present work facilitated synonymization with the convalidated species of *Cannanoropollis*. Unfortunately, many slides of type species are missing, including the type species *Parasaccites korbaensis*. In those cases, we based our analysis on original diagnoses and illustrations.

Among the remaining species erected under *Parasaccites,* they have been synonymized under the convalidated species of *Cannanoropollis* based on their original/emended diagnoses, viz., *C. janakii*, *C. densus*, and *C. triangularis*. Some have been transferred to other genera, such as *Caheniasaccites* and *Potonieisporites*, as they differ from *Cannanoropollis*.

Acknowledgments
Director BSIP and Ministry of Earth Sciences (MoES/P.O. (Geo)/211/2019).

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Further comments on "Uppermost Permian to Lower Triassic conodont biostratigraphy and carbon isotope records from Southern Armenia," by Han et al. (Palaeogeography, Palaeoclimatology, Palaeoecology, 667 (2025) 112,870)

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As outlined by Horacek et al. (2025), Han et al. (2025) publication on 'Uppermost Permian to Lower Triassic conodont biostratigraphy and carbon isotope records from Southern Armenia' contains several shortcomings. Here we suggest further published research and alternative methodology that should be considered alongside Han et al. (2025) to gain a more accurate understanding of the Southern Armenian setting.

In the Introduction section of Han et al. (2025), the history and controversies surrounding the well-exposed Upper Permian to Lower Triassic marine carbonate deposits in Southern Armenia, that were first presented by Baud, (2014, chap. "Transcaucasia", p. 8) and later well developed by Sahakyan et al., (2017a, chap. 2 -Overview on Permian-Triassic stratigraphy) were not reported.

In regard to the conodont succession, comparisons could be made to Bagherpour et al. (2017), who suggested a similar Permian-Triassic conodont succession and a similar onset of microbialites in the Triassic of South China. And specifically for the Permian-Triassic in Armenia, we suggest the utilization of Unitary Association Zones as shown by Brosse et al. (2015, 2016) in South China. We believe this provides a better approach to fine biochronology and correlations in this area rather than the diachronous fossil first occurrence method (FO) proposed by Han et al. (2025).

Han et al. (2025) statement that 'the position of the PTB in Armenian sections and its correlation with other well-studied successions, in terms of both conodont biozones and carbon isotope records, remain insufficiently understood,' is questionable. Sahakyan et al. (2017a, b), provides substantial insight into precisely these issues. Furthermore, while working on the biostratigraphy, Han et al. (2025) apparently ignore that key macrofossils are as important as microfossils and conodonts. In the 'Geological setting' section, critical faunal and lithological data documented by Aslanian (1984), including a diverse ammonoid and nautiloid assemblage (nautiloid *Foordiceras* (?) cf. *grypoceroides* and ammonoids *Shevyrevites* sp., *Paratirolites dieneri*, *P. kittli*, *P. waageni*, *P. vediensis*, *P. trapezoidalis*, *Abichites mojsisovicsi*, *A. stoyanowi*, and *A. abichi*) within the *Paratirolites* limestone (Fig.1), was not cited. This undermines the biostratigraphic framework and leads to an incomplete understanding of faunal turnover across the Permian-Triassic boundary. Similarly, the basal Triassic macrofauna (*Claraia* and

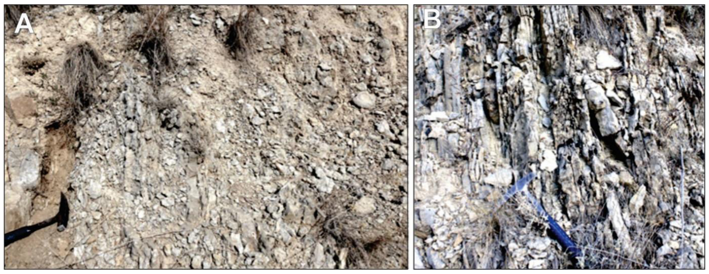

Fig. 1. The Vedi section. A- view on the top of the thin bedded *Paratirolites* limestone, in gray color; B- main part of the nodular *Paratirolites* limestone. Hammers for scale-25 cm.

Lytophiceras) reported from the first limestone beds above the *Paratirolites* limestones, the strata that contain the conodont *H. parvus* published by Zakharov et al., (2005), are not accounted for. Despite the significance of these findings, Han et al. (2025) fail to acknowledge or discuss the biostratgraphical significance of this important faunal record, leading them to rejuvenate the PTB based on the FO of *I. isarcica*, together with *H. parvus*.

It appears that Han et al. (2025) confused the first occurrence (FO) recorded in their samples with a first appearance (FA) in the sections on “modern taxonomic frameworks” and “updated conodont occurrences”. This led them, in the examined Armenian sections, to replace the well-established Triassic *parvus* conodont zone with their Permian *praeparvus* zone, and in fig. 11 to correlate *parvus* FO in Armenia to the First Appearance Datum (FAD) defined in Meishan. Then the use of carbon isotope records for correlation became much easier.

Consequently, rather than making progress, this is a step backwards in stratigraphic science. Rigorous stratigraphic methodology, as emphasized by Horacek et al. (2021, 2022 and 2025), Baghepour et al. (2017) and Brosse et al. (2015, 2016), is essential for ensuring the accuracy and reliability of such studies in biostratigraphy and biochronology.

Furthermore, Han et al. (2025) publication reflects a disregard for adhering to the principles of the Institute of Geological Sciences (IGS), the National Academy of Sciences of the Republic of Armenia in Yerevan, and UNESCO, and the approved Armenian protocols governing the exportation of geological samples. The authors also failed to acknowledge the 2017 invitation and the welcome extended by IGS, as well as detailed presentations and guidance from the hosts.

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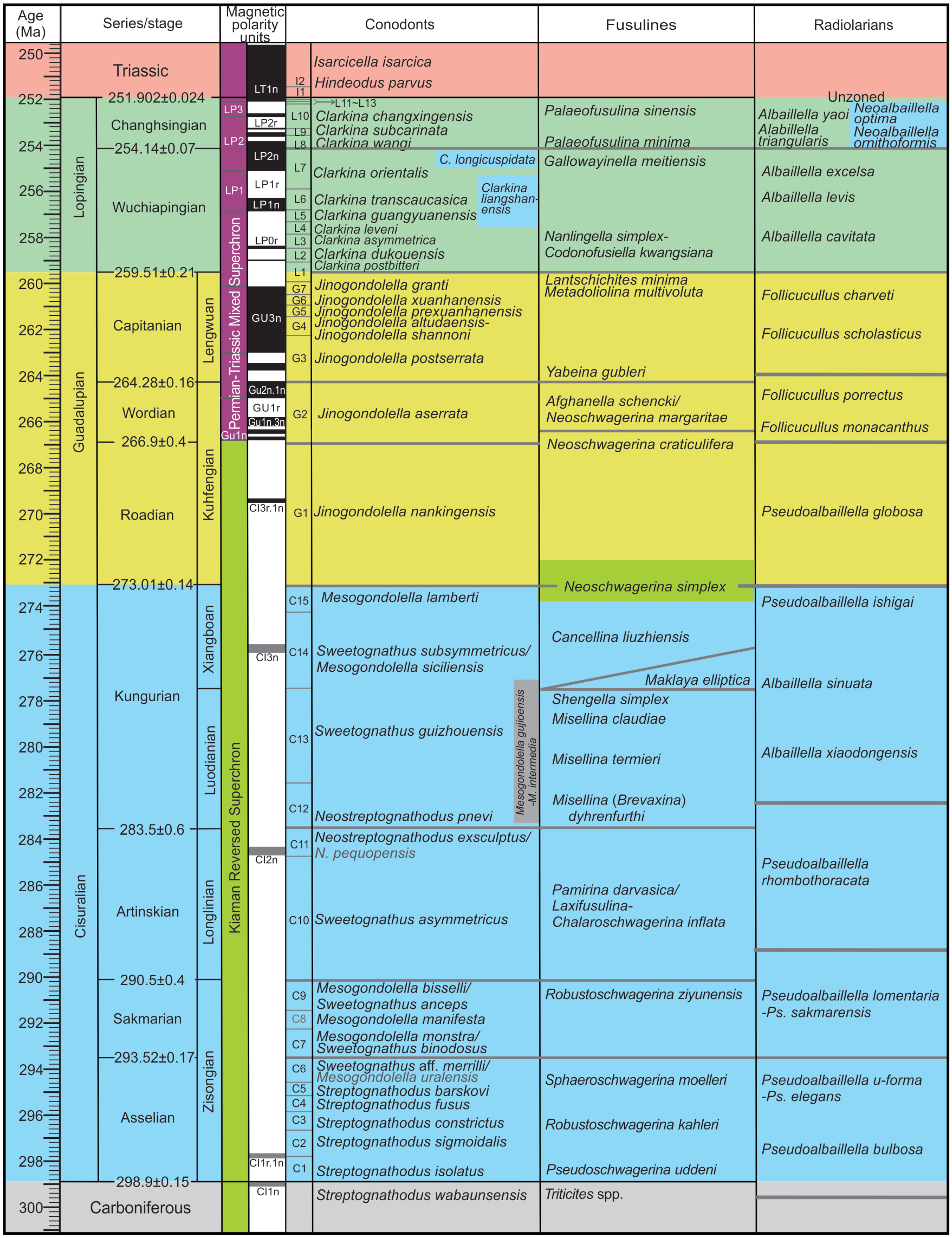

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