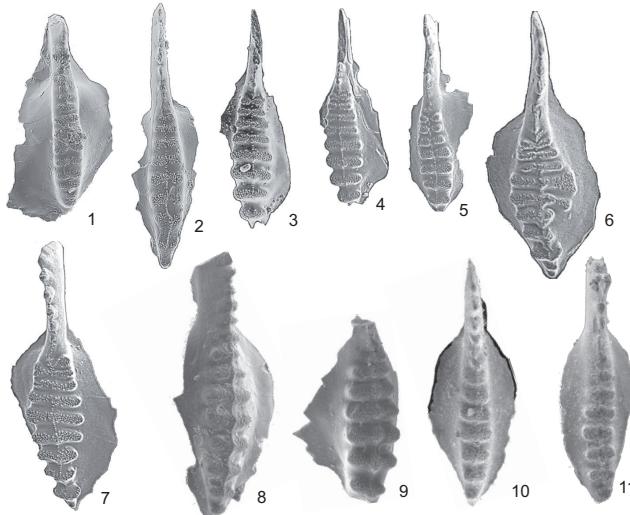
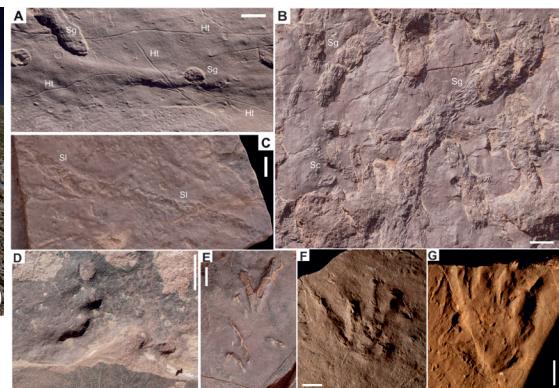
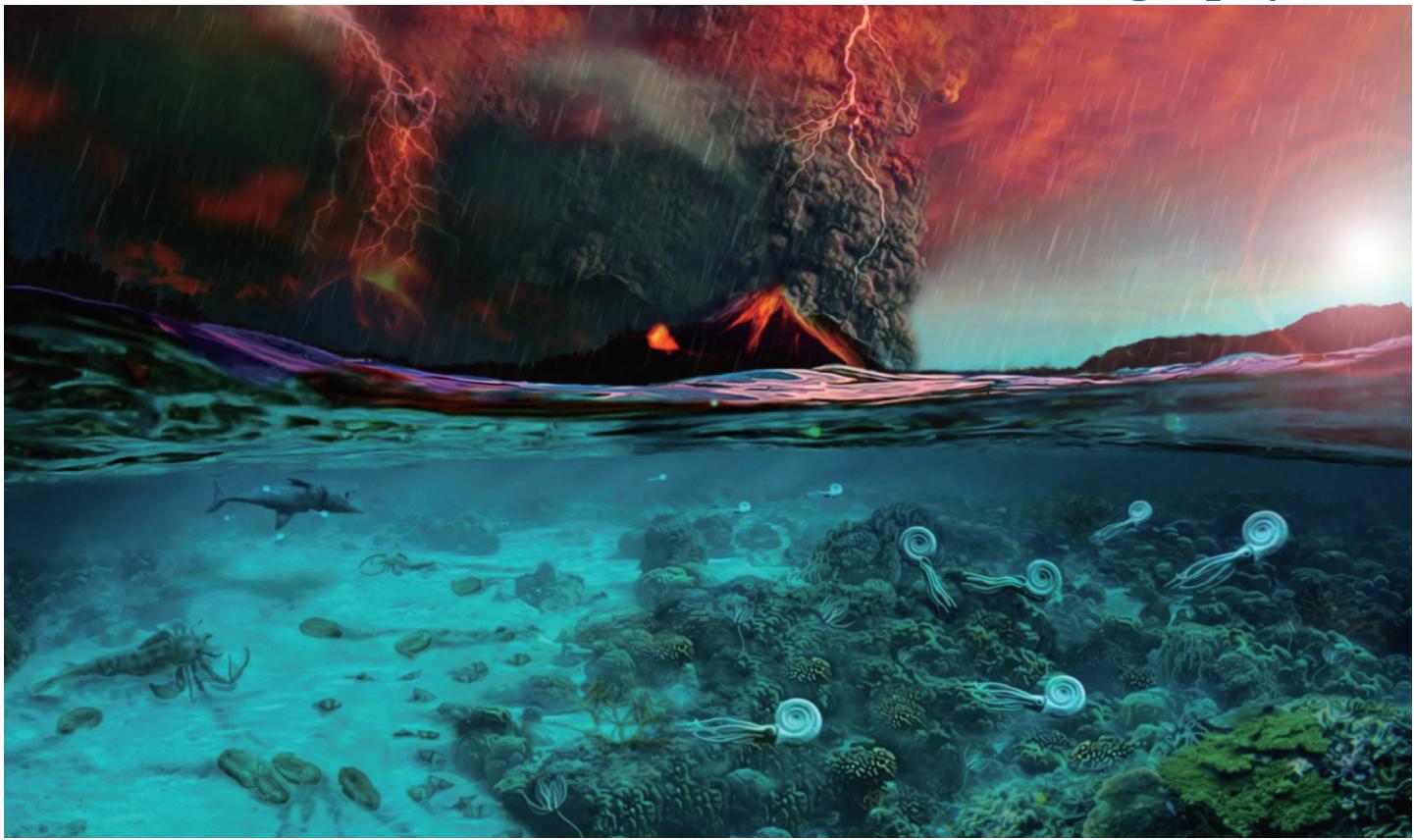




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International Commission on Stratigraphy



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Notes from the SPS secretary

Yichun Zhang

Introduction and thanks

During this busy time, Lucia Angiolini and I prepared this issue of *Permophiles* 70 via frequent email communications, as we had no opportunity to meet due to severe Covid-19 virus restrictions around the world. Even if the interval between the last issue and the current issue was very short, we received many contributions for this issue. It is clear that Permian scientists are very active in Permian research and keen to discuss significant Permian topics!

During the last months, I worked to design and organize a new Permian website (<http://permian.stratigraphy.org/>). I would like to thank Nicholas Car (webmaster of ICS) who assisted me in building our new website. I also thank many researchers who kindly provided the photos for the website. The new website will be released soon. In the new website, besides an update on the Objectives, Members, Working groups, GSSPs, Time scale, Publications, there is a new section with topics of interest to all the members. At the moment it comprise a compilation of the papers published on Permian topics in 2020. This work was commissioned to Claudio Garbelli by the SPS executive. Thanks to Claudio for his hard work. The 2020 reference list will also be included at the end of this *Permophiles* issue. Here, I would like to encourage Permian workers to share their work on the website at any time, and suggest publications to be added to the list (for the moment just papers published in 2020).

This issue of *Permophiles* contains contributions covering many aspects of our Permian study including biostratigraphy, high-resolution dating, palaeogeography, end-Permian mass extinctions and field reports. Many thanks to the contributors of this issue: Charles M. Henderson, Valery V. Chernykh, Spencer G. Lucas, Amal Zouicha and co-authors, Luca G. Costamagna, Harald Lützner and co-authors, Michael H. Stephenson and Dorit Korngreen, Hana Jurikova, Micha Horacek and co-authors.

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This issue contains fruitful contributions on diverse aspects related to Permian studies. Charles Henderson and Valery Chernykh have agreed to use *Sweetognathus asymmetricus* to replace *Sw. whitei* to define the base of the Artinskian stage. The emended description of *Sw. asymmetricus* and its wide distribution and potential global correlation hold promise for defining GSSP at the Dal'ny Tulkas Section.

Spencer G. Lucas reviewed the substages of Permian. He strengthened that subdividing the substages of Permian is the future work of SPS. We acknowledge such proposal.

Amal Zouicha and co-authors reported tetrapod ichno-assemblages from the Koudiat El Hamra-Haiane basin of Morocco. These trace fossils suggest the age to be Artinskian to Capitanian for the red beds in the basin.

Luca G. Costamagna reported his work in the Mulargia-Escalaplano molassic basin in Sardinia, Italy. By studying the depositional facies of the Rio Su Luda and Mulargia formations, he proposed a pull-a-part basin model.

Harald Lützner and co-authors reported recent high-resolution TIMS ages on the volcanic rocks in the Thuringian Forest Basin of Germany. These new data allow to update the ages of many formations in the basin and help in defining the Carboniferous-Permian Boundary in the basin. More significantly, the duration of the volcanic activity in this basin was shorter than previously recognised.

Michael H. Stephenson and Dorit Korngreen have reported their recent work in the Permian of the Negev desert of Israel and Jordan. The correlations of Permian sequences among Israel, Jordan, Saudi Arabia and Oman allowed the authors to recognise a significant diachronous onset of marine limestones from Oman to Israel.

Hana Jurikova summarised the key findings and implications of a recent geochemical work on the Permian-Triassic mass extinction. The modelling based on pH data from brachiopods and global carbon isotope records suggests a sudden and steep release of CO₂, which triggered the end-Permian mass extinction.

Yichun Zhang and co-authors reported their recent fieldwork in northern Tibet. The different Permian sequences and faunas are significant for palaeobiogeographic and palaeogeographic reconstructions.

This issue ends with a last minute contribution by Micha Horacek and co-authors which contains a discussion about a paper by Chen et al. recently published on the famous Abadeh section in Iran. We welcome and wait for a reply by Chen and co-authors and remind all Permian workers that *Permophiles* is a forum for discussion on Permian topics.

Future issues of *Permophiles*

The next issue of *Permophiles* will be the 71st 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 71 is 31 July 2021. Manuscripts and figures can be submitted via email address (yczhang@nigpas.ac.cn) as attachment.

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

Notes from the SPS Chair

Lucia Angiolini

In last *Permophiles* issue, the new executive was presented, along with the main goals for the next term. The new SPS executive started to work to promote collaboration among Permian workers and to widen the Permian community, by organizing two webinars. The first (22 October 2020) was restricted to voting members and has been already reported in *Permophiles* 69, while the second (13 November 2020) was open to the corresponding members and it is described in the present issue.

The results of these webinars are now coming to fruition, as demonstrated by the conspicuous contributions presented for this issue. This is an important step forward for the completion of the

GSSPs for the Permian System.

The work of Valery Chernykh and Charles Henderson, presented in this issue with the evocative title “TO BE OR NOT TO BE *Sweetognathus asymmetricus*?””, allows the executive to turbocharge the Artinskian-base GSSP.

The candidacy of the Dal’ny Tulkas section to define the Artinskian-base GSSP was published many years ago in *Permophiles* 58 (Chuvashov et al., 2013) and updated in *Permophiles* 69 (Chernykh, 2020). The section and point are promising, as sedimentation is continuous and there are several bioevents to mark the boundary and use for correlation: conodonts, fusulines, ammonoids. There are geochronologic ages, and C and Sr isotope data. The main problem, discussed in the SPS voting member webinar, was the name of the defining conodont species *Sweetognathus whitei*.

However, based on the important contribution published in this issue, it is clear that the successful collaboration between Valery and Charles lead to the solution of the main objection regarding this taxon and thus the removal of the main obstacle in defining the GSSP at Dal’ny Tulkas.

I thus kindly ask all SPS voting and corresponding members to read carefully the taxonomic agreement of the two conodont specialists and provide comments and contributions by the end of February.

A revised proposal will be sent to voting members by April, with a request for comments before voting, followed by call for a vote of voting members in summer 2021.

Other ongoing activities include the construction of the new SPS website by the SPS secretary Yichun Zhang with the help of Nicholas Car, of SURROUND Australia. For this, I warmly thank Yichun for his very hard work (also in editing *Permophiles*) and those of you who have provided photos for the website and the revised working group descriptions.

The website is available now to all of you and it will be supplemented by a video to advertise the Permian to a wide audience. This is still under construction.

Last, but not least, the vice-chair Mike Stephenson and I have discussed the topics of the next webinars.

The first already scheduled will be “Uses and abuses of radiometric data for Permian workers” by Mark Schmitz, Boise State University and will be held on 1st April 2021 at 16.00 European time with the help of organization by Jeanine Newham of BGS.

The second will be held after the summer and will be focused on “Uses and abuses of palaeogeographic reconstructions for Permian workers” by Giovanni Muttoni, Università di Milano.

We will keep you informed on all ongoing activities also through the new website.

ANNUAL REPORT 2020

1. TITLE OF CONSTITUENT BODY and NAME OF REPORTER

International Subcommission on Permian Stratigraphy (SPS)

Submitted by:

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2. OVERALL OBJECTIVES, AND FIT WITHIN IUGS SCIENCE POLICY

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

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

3. ORGANISATION - interface with other international projects / groups

3a. Officers for 2020-2024 period:

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

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

5. CHIEF ACCOMPLISHMENTS IN 2020 (including any relevant publications arising from ICS working groups)

- General proposals for the bases of the Artinskian and Kungurian stages have been prepared and published in the SPS Newsletters *Permophiles* 69 by Chernykh (2020).
- A multidisciplinary study of the Mechetlino Quarry section (Southern Urals, Russia), the GSSP candidate for the base of the Kungurian Stage has been published by Chernykh et al. (2020, *Palaeoworld* 29).
- The Sakmarian-base GSSP by Chernykh et al. has been accepted for publication in *Episodes* in April 2020.
- Two issues of *Permophiles* have been published (SPS Newsletters *Permophiles* 68 and 69)
- The Guadalupian timescale has been refined based by Wu et al. (2020, *Palaeogeography, Palaeoclimatology, Palaeoecology*, 548). A comprehensive paper on the three GSSPs and their correlation of the the Guadalupian Series has been published (Shen et al., 2020, *Earth-Science Review*, 211)
- A comprehensive review of the terrestrial Permian stratigraphy has been provided by Schneider et al. (2020, *Palaeoworld*, 29).
- A voting members webinar has been organized on 22 October 2020.
- A corresponding members webinar has been organized on 13 November 2020.

6. SUMMARY OF EXPENDITURE IN 2020

No expenditure was incurred in 2020 due to the health emergency for Covid-19 which prevented travel for congresses and field trips.

7. SUMMARY OF INCOME IN 2020

An amount of Euros 3356,84 was allocated from ICS.

8. BUDGET REQUESTED FROM ICS IN 2021***

We apply for 5700 US\$ from ICS for SPS activities in 2021. This will be mainly for the activities to turbocharge

first the establishment of the base-Artinskian GSSP at Dal’ny Tulkas section, Russia and then the base-Kungurian GSSP at Mechetlino, Russia, and to organize (if possible depending on the development of the Covid-19 emergency) a voting members field trip in the area.

We will use a part of the money for producing a professional video to advertise SPS and eventually for some publication costs.

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

- We plan to ratify the GSSP of the base of Artinskian and start to work on that of the base of Kungurian.
- We plan to produce a video to advertise SPS.

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

- Establish the Artinskian and Kungurian GSSPs.
- Revise the Permian timescale where it needs to be improved (Guadalupian stages, replacement GSSP section of the base-Lopingian).
- Establish a robust palaeogeographic frameworks for the Permian and focus on N-S correlations.
- Propose DDE-sponsored informatics support for biostratigraphic data management and palaeogeographic reconstructions.
- Organize webinars to increase the size, diversity and international coverage of the Permian Community
- Publish at least two *Permophiles* issues each year

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

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1) Artinskian-base and Kungurian-base GSSP Working Group;
Chair-Valery Chernykh.
2) Correlation between marine and continental Guadalupian
Working Group; Chair-Charles Henderson.
3) Correlation between marine and continental Carboniferous-
Permian Transition Working Group; Chair-Joerg Schneider.

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Report of SPS corresponding members meeting on 13 November 2020

On 13 November, 2020, the SPS Chair Lucia Angiolini and Vice Chair Mike Stephenson, with the help of Jeanine Newham (BGS), organized a zoom webinar for the corresponding members.

Twenty-six persons from different parts of the world attended the webinar: Deepa Agnihotri, Lucia Angiolini, Sylvie Bourquin, Simonetta Cirilli, Luca Costamagna, Eliana Coturel, Giusy Forte, Claudio Garbelli, Charles Henderson, Hana Jurikova, Leopold Krystyn, Evelyn Kustatscher, Ruslan Kutygin, Lance Lambert, Lorenzo Marchetti, Giovanni Muttoni, Tadeusz Peryt, Ausonio Ronchi, Tamra Schiappa, Joerg W. Schneider, Lucas Spencer, Amalia Spina, Mike Stephenson, Geoff Warrington, Liz Weldon, Dungxun Yuan and Yichun Zhang.

The agenda of the meeting comprised the following topics: an Introduction to the SPS by Lucia Angiolini, a presentation on the continental Permian by Joerg W. Schneider, a presentation on the marine Permian by Charles Henderson, Break Out sessions to discuss issues of the Permian, and final comments.

In the introduction, Lucia Angiolini presented the main objectives of SPS which are: 1) to define the series and stages of the Permian by means of internationally agreed GSSPs and to establish a high resolution temporal framework based on multidisciplinary approaches; 2) to provide the international forum for scientific discussion and interchange on all aspects of the Permian, specifically on refined intercontinental and regional correlations. Then, she presented the already ratified Permian GSSPs and the two missing ones, the Artinskian and Kungurian GSSPs.

The main goal of the Executive for next year is to turbocharge the Artinskian-base and Kungurian-base GSSPs to complete the Permian System. The candidates are: Dal'ny Tulkas section, Bashkortostan, Russia for the base-Artinskian and Mechetlino, Bashkortostan, Russia for the base-Kungurian. Additional goals are to frame all Permian events into the time scale: evolution, climate, palaeogeography, marine and continental correlations, to revise the timescale where it needs to be improved and to increase the size, diversity and international coverage of the Permian Community. The Break Out sessions were organized for this purpose, to discuss together issues of the Permian, stimulate circulation of ideas and thoughts, and receive more contributions from a larger number of researchers.

After the introduction, two very interesting presentations were given by Joerg W. Schneider and Charles Henderson. These are summarized below in the two abstracts they kindly provided.

Summary of the SPS Webinar presentations

Permian nonmarine-marine correlations: State of the art – future tasks

By Joerg W. Schneider and the Late Carboniferous - Permian - Early Triassic Nonmarine-Marine Correlation Working Group

The presentation provided an overview of the progress made by the members of the Late Carboniferous - Permian - Early

Triassic Nonmarine-Marine Correlation Working Group since 2013/2014. Details are published in the report of the group given by J.W. Schneider in *Permophiles* 69 (2020). The most important outcome was a compilation of nonmarine biostratigraphic methods suitable for long-range correlations and the connection of nonmarine sections to the marine Standard Global Chronostratigraphic Scale (SGCS), published by an international team of 18 authors (Schneider et al., 2020). Based on this, the following conclusions were drawn in the Webinar:

1) Climate results from interference between processes in the oceans and on the continents. We need to understand this coupled land-sea system for the understanding of ancient ecosystems and for the prediction of present and future processes on Earth.

2) Late Pennsylvanian, early to middle Cisuralian as well as Lopingian and Early Triassic nonmarine-marine correlations have already reached a good level. Late early Cisuralian and Guadalupian nonmarine biostratigraphy and connections to the SGCS are still unsatisfactory. Among other regions, the well exposed and fossiliferous late early Permian to Early Triassic deposits on the East European Platform bear a high potential for the solution of this problem.

3) The most challenging future task for nonmarine-marine correlations in the Late Carboniferous–Middle Triassic are global north-south correlations. Biostratigraphic correlations among the biotic provinces of Euramerica, Angara, Cathaysia, and Gondwana are still in a very unsatisfactory state. Sections of the East European Platform and Siberia in Russia, those of the Karoo basin in South Africa, sections in North China, in Jordan and North Africa as well as in the Paraná basin of South America should be a focus of further research of the SPS.

To promote progress a call for global cooperation in the correlation of the most important and well investigated continental and mixed marine-continental basins as well as for the establishment of regional continental reference sections will be published in the next issue of *Permophiles*.

References

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The Marine Permian

by Charles Henderson

The presentation started with an historical review of the establishment and subdivisions of the Permian system, from Murchison in 1841 to the heated debate on the number of series at the 1991 Perm meeting and finally to the paper by Jin et al., 1997 in *Episodes*, a classic compromise that has directed the activities of SPS ever since. An important aspect of the original Permian and all modifications was “looking at the rocks”, as

there are common signatures, for example, cycloths of the Asselian and major 3rd order sequences and flooding surfaces in the Sakmarian and Artinskian and above. The importance of not being detached from the rock record while we also consider taxonomic issues was underscored in the webinar and several sections were shown: the SW Ellesmere Island sections, which includes 1100 metres of cyclic (glacial-eustatic control) upper Kasimovian to lowermost Sakmarian; the GSSP at the Aidaralash section; the GSSP for the base-Sakmarian at the Usolka section, which includes facies that are similar to the central Sverdrup Basin Hare Fiord Formation; the proposed base-Artinskian GSSP at Dalny Tulkas in the southern Urals characterized by a strong rock signature and many fossils and U-Pb age dates and stable isotopic signals, all available for broader correlation; and the proposed base-Kungurian GSSP Mechetlino section, with a conodont succession identical at the Rockland section in Nevada and also in the Sverdrup Basin, demonstrating widespread, but not global, correlation for this Cisuralian (Lower Permian) stage.

Above this level in Russia, the succession is dominated by non-marine facies with some restricted marine, so the presentation moved to west Texas to define the Middle Permian or Guadalupian. In a recent paper, Shen et al. (see *Permophiles* 69 for Guadalupian report) show the geochronologic ages and fossils that assist correlation between south China and west Texas, but they conclude that the base-Roadian, base-Wordian and base-Capitanian GSSP definitions may need some minor revision or fine-tuning in the area. The outcrops in the Guadalupe Mountains National Park are outstanding as shown by the slides, for instance that of stratotype canyon, the GSSP for the base-Roadian, and these carbonates are subject to many sequence stratigraphic analyses (Kerans et al., 2014). The recognition of conodont geographic clines within transgressive facies allows the correlation of the base-Roadian into the Canadian Arctic, but strong provincialism limits correlation of younger units. The Middle Permian includes extensive carbonate platform deposits in the Maokou Formation of south China.

The Delaware Basin in west Texas became isolated, resulting in the deposition of evaporites, so the presentation moved to South China for the best Upper Permian (Lopingian) fossiliferous carbonates, deposited within the equatorial zone. The base-Lopingian (base-Wuchiapingian) GSSP at the Penglaitan section along the Hongshui River (Laibin, Guangxi) was flooded due to a new dam, but a nearby site is being intensively studied as a substitute. The GSSP at Penglaitan is really a natural boundary as it occurs near the correlative conformity within lowstand deposits. By having the GSSP within the lowstand, it means that rocks above the sequence boundary in other parts of the world are always Lopingian. The base-Changhsingian GSSP was celebrated at Meishan in 2006 at the same site where the base-Induan (base-Triassic or top-Permian) was celebrated in 2001. A Geopark was created to recognize these two GSSPs, which makes the location the body stratotype for the Changhsingian.

The presentation transported participants through 47 million years from the base Permian at 298.9 Ma to the top at 251.9 Ma. The greatest mass extinction in Earth history (EPME) occurred just before the end (251.94 Ma), and briefly the world was dominated by microbial units that span the PTB. The talk

concluded that there is still work to do, first to complete the Permian GSSPs (base-Artinskian, base-Kungurian). But when we do, the Permian community should focus on looking at the entire Permian rather than focusing on only the boundaries. With the completion of the marine Permian time scale, there should be a renewed focus to consider marine-continental correlations. The final statement was “don’t forget the rocks”.

A series of Break Out sessions were held as part of the webinar, where each of the Break Out groups was assigned a questions to discuss and answer. A spokesperson from each group then reported back. The reports are provided in note form below.

Comments from Group 1

Reported by Evelyn Kustatscher

Question: What is the most important scientific question to be answered in the Permian?

A synopsis of the group’s answers: The most important scientific questions are 1) Accessibility of Palynological data: Data from palynology from the oil drilling companies are not accessible. 2) Most of the charts (Palaeogeography, biomes, palaeoclimate maps) that we are dealing with are some 20 years old but we still use them because there are few or no alternatives at the moment. 3) Correlation marine/no-marine successions. 4) How/why and when of the end of the Permian glaciation? Also when and how of the Permian glaciations? 5) What about the Guadalupian/Lopingian extinction? 6) Vegetation changes that might influence sedimentational rates? 7) Sea-level changes: what effect does it make on preservation/environmental of fossils in the sediments? 8) How does the climate change, how can we get to much higher resolution correlation? The seasonality, the latitudinal gradients? How can we improve/track this? 9) Why not reconsider the Permian from the scratch: produce new palaeographic maps based on sedimentologically sensible datasets that are updated?

Comments from Group 2

Reported by Charles Henderson

Question: What are the main palaeontological gaps in Permian studies?

The following gaps were discussed. 1) The Middle and Upper Permian continental record in Russia and South Africa (and other regions), especially of the vertebrate succession. 2) The correlation of marine and continental successions, especially where they interfinger, through increased use of palynostratigraphy. 3) Middle Permian provincialism means we should be looking more at the similarities (clines) rather than the differences (taxonomic over-splitting) of conodonts and fusulinaceans, but also other invertebrates to reduce correlation gaps. This could mean a North-South consideration as mentioned by Joerg W. Schneider in his presentation on the continental Permian record. 4) It was noted that one gap is with taxonomy, this must still be emphasized, for microflora, but also all fossil groups. 5) There could be a concerted paleontologic focus on better integrating some of the regional scales (e.g. Wolfcampian and Leonardian) with the global time scale. 6) Finally, the fact that we have focussed on boundaries to define GSSPs has left

many gaps – in other words, we agreed that it is important to emphasize the entire Permian, including how the biotic record is affected by climate change and paleogeography.

Comments from Group 3

Reported by Hana Jurikova

Question: Is it important to have an updated website for the Permian? How should *Permophiles* be developed?

A synopsis of the group's answers: 1) We need a website to include all Permophile issues, collect all submission work, all Permian works published, have a forum, etc. We need a members' page as well a page for the general public. 2) How to build it? We need an infrastructure, and regular updates are very important. ICS needs to be consulted to see if possible to make it in the framework of the ICS website. Eventually organize a call to find people who can help in structuring and managing the website. 3) *Permophiles*: we need more contributions, for example summaries / advertisements of recently published works and we need to attract younger researchers.

Comments from Group 4

Reported by Spencer Lucas

Question: How do we build the Permian community? How do we get young researchers interested in Permian stratigraphy?

A synopsis of the group's answers: 1) Identify important and interesting problems of Permian Earth history that can only be resolved with a strong grasp of timescale and correlations. 2) Emphasize that Permian timescale problems are global problems that require integration of marine and nonmarine datasets, necessary to the ordering of Permian Earth history—in other words, “sell” the timescale research based on its great relevance to all aspects of understanding the Permian World.

Comments from Group 5

Reported by Liz Weldon

Question: What do we do next, after the establishment of GSSPs?

A synopsis of the group's answers: 1) Focus on north-south correlations. 2) In several countries (e.g. India) it is difficult to find boundaries and there are no radiometric dates, in others (e.g. UK, Australia) there are problems of correlation with the International Time Scale. 3) Focus on breaks in sequences. 4) Focus on land-marine correlation to make the Permian more relevant. 5) *Permophiles* should continue to provide a forum for discussion and amendments of boundaries.

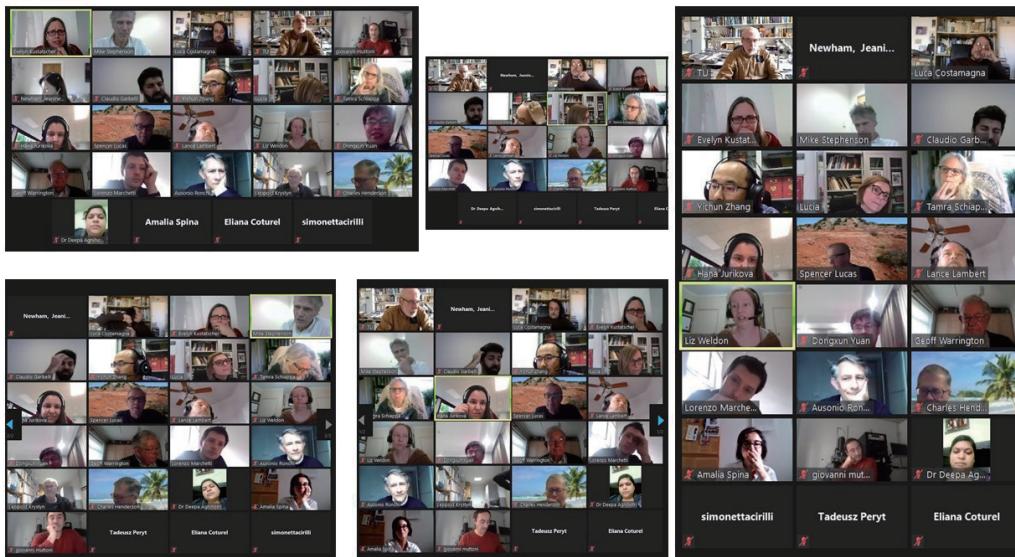
To conclude, the Break Out sessions were really stimulating and many topics were discussed and proposed to continue the studies of the Permian.

Among the most relevant issues that should be addressed in the near future to “fit the whole Permian world into this timescale” (cit. Spencer Lucas), are for certain North-South correlation, correlation of marine and continental successions, especially where they interfinger, and correlation of regional scales with the global time scale. These were the most reported topics during the Break Out sessions. Correlation is the watchword. However, to achieve correlation we need more robust and up-to-date palaeogeographic maps. Palaeogeography is thus the other main topic to develop. Palaeoclimate is also of concern and it also requires a good palaeogeographic base.

To build the community and attract young scientists we need to better advertise timescale research and show how this is important to understand the Permian world. We need also a good, attractive and interactive website not only for Permian researchers but for the wider audience. And finally, we need to keep *Permophiles* going as a great forum for Permian discussion, and for soliciting and providing more and more contributions.

As additional information, immediately after the webinar, the ICS executive was contacted on the website question, and the SPS website is currently being deployed and updated in the main ICS site by Nick Car (Canberra, Australia) with Yichun Zhang.

Lucia Angiolini, Michael Stephenson and Yichun Zhang



Screenshots from the 13 November webinar

TO BE OR NOT TO BE *Sweetognathus asymmetricus*?

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Introduction

A preliminary proposal to define the base of the Artinskian GSSP at the Dal'ny Tulkas section was published in *Permophiles* 58 in 2013 (Chuvashov et al., 2013). There have been few objections regarding the proposed section and point because there are many markers for correlation including conodonts, fusulinaceans, ammonoids, sequence stratigraphy, stable isotopes and geochronology. The main objection was the name of the defining taxon (*Sweetognathus whitei*) as well as the need for details regarding its lineage (see Henderson, 2020).

This short note confirms that Valery Chernykh and Charles Henderson agree that the defining taxon is not *Sw. whitei*, but rather it should be referred to *Sw. asymmetricus*. We provide details regarding this conclusion below.

Stratigraphic occurrences and homeomorphy

The sediments of the Artinskian Stage in the Dal'ny Tulkas section proposed as the GSSP of the base of this stage contain forms originally identified as *Sweetognathus whitei* (Rhodes). The low quality depiction of the holotype and paratype in the work of Rhodes (1963) make direct comparison difficult. Furthermore, the first description of *Spathognathodus whitei* Rhodes from the top of the Tensleep Formation in Wyoming, did not provide the full range of morphology. The assignment of the Uralian forms to this species was not determined by their comparison with specimens from Tensleep (Wyoming). Rather, the work of Ritter (1986, 1987) was used to identify the Uralian specimens. The Uralian forms correlated well with the Artinskian forms from the Riepetown Formation, Moorman Ranch (Nevada), which were identified by Ritter as *Sweetognathus whitei*. However, we now know that those Riepetown specimens differ in morphology and occurrence from specimens associated with the Tensleep Formation and Florence Limestone in Kansas.

This homeomorphy remained unrecognized for a long time. In retrospect, it should have been recognized that equating specimens of *Sw. whitei*, recovered from cyclothsems in association with species of *Streptognathodus*, with specimens of *Sw. whitei* from non-cyclothemtic succession without *Streptognathodus* was a problem. The first hint of this taxonomic and stratigraphic problem appeared when Mark Schmitz dated zircons in ash beds from Bolivia that demonstrated that some species of *Sweetognathus* were Asselian in age (Henderson et al.,

2009). After considerable research, Henderson (2018; online in 2016), determined that there were two lineages and two forms referred to as *Sweetognathus whitei*; he referred the younger new species initially to *Sw. aff. whitei*. From this point, the species independence of Artinskian sweetognathids from Uralian sections was clear. This new species was named by Sun and Lai (Sun et al., 2017) from lower Chihsia strata at Tieqiao section in South China as *Sweetognathus asymmetricus* (note: we have changed specific adjectival ending to match genus). Finally, the significance of *Sweetognathus asymmetricus* and its placement within a distinct lineage was demonstrated using detailed morphometric analysis (Petryshen et al., 2020). It turns out that the original *Sweetognathus whitei* is late Asselian. We have carefully reviewed all previously used material when determining the species-indicator (*Sw. asymmetricus*) for the lower boundary of the Artinskian Stage.

Conclusions

The main conclusion from our work presented here is that the Uralian Early Artinskian forms are not *Sw. whitei* (Rhodes), but rather *Sw. asymmetricus* Sun and Lai. The main difference between the Uralian forms of *Sw. asymmetricus* and the topotype specimens of *Sw. whitei* from Wyoming is the construction of the carina. In the upper view, nodes exhibit rhomboid outlines, are somewhat flattened and wider in the Uralian forms, and narrower and variably elevated above the platform in typical *Sw. whitei*. The margins of nodes are sloped and the pustulose microornament very irregular in *Sw. whitei*. The steep margins of nodes in *Sw. asymmetricus* confine the microornament to only the top surface of the nodes (or transverse ridges).

The asymmetric construction of the anterior transverse ridges is not an obligatory feature of *Sw. asymmetricus* Sun and Lai as the authors of the species claim. This feature can be noted in the description of the species, as it is observed in some specimens (Plate 1, fig. 6). But as the main feature of the *Sw. asymmetricus*, this feature of the structure of the anterior carinal teeth is not diagnostic of the population. For example, in the depicted specimens found in the upper part of bed 4 and bed 5 in the Dal'ny Tulkas section (Plate 1, figs. 2, 3), the structure of the anterior carinal ridges is symmetrical. The same structure can be seen in specimens of this species from the same section from the clarki Zone (Artinskian stage, Irginian horizon) – as seen in Plate 1 (figs. 4, 5). It would hardly be justified to attribute these specimens to some new species only on the basis of the fact that they have symmetrically constructed anterior carinal ridges.

The typical Early Artinskian forms of the species *Sw. asymmetricus* have one more feature that should be included in the diagnosis – the presence of a fully developed or partially reduced median ridge between the transverse carinal ridges. It consists of single row of pustules closely adjacent to each other and linearly located. In the Early Artinskian forms of the Bursevian Horizon, the median ridge is located on the platform surface, adjacent to the transverse carinal ridges, but does not go over them from above. In the forms of the Irginian horizon, the median ridge can be located both between and above the carinal ridges (Plate 1, figs. 4-6). At the same time, a partial reduction of the carinal ridges is also observed in the Irginian forms. We

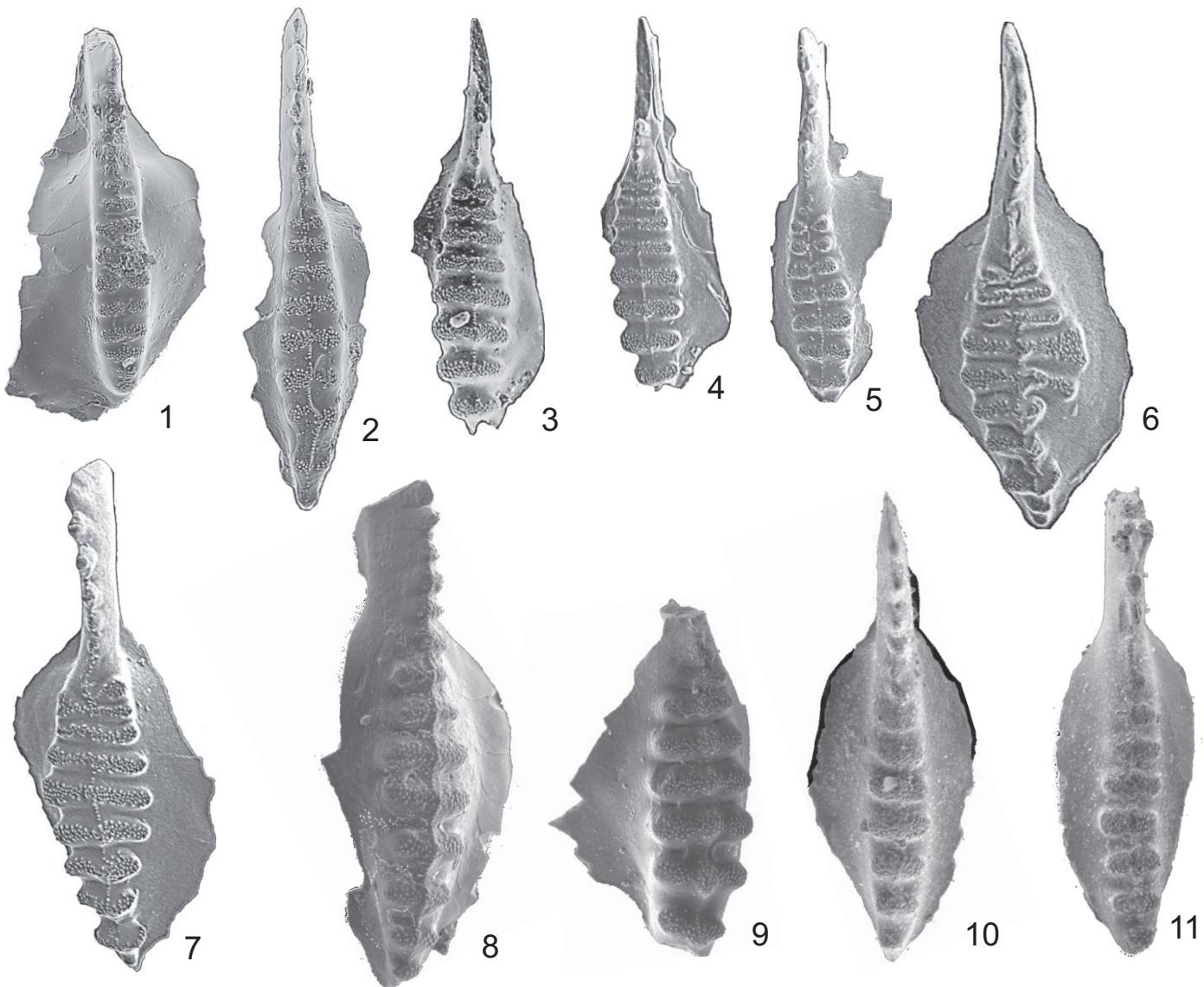


Plate 1. *Sweetognathus asymmetricus* Sun and Lai from deposits of the Artinskian stage of the Dal'ny Tulkas section, from the type locality in south China, and from Carlin Canyon, Nevada. Same magnification with average length of ~1 mm.

1. DT-18a, transitional form from *Sweetognathus anceps* Chernykh to *Sw. asymmetricus* Sun and Lai;
 2. DT-18b, typical specimen with a fully developed median ridge; bed 4b, Bursevian horizon, *asymmetricus* Zone;
 3. T-19-3, specimen with symmetrically built carina, bed 5, Bursevian horizon, *asymmetricus* Zone;
 4. DT40-29, median ridge is located above the upper surface of the carinal ridges;
 5. DT40-17, the median ridge is located below the upper surface of the carinal ridges;
 6. DT40-19, anomalous specimen with relics of the median ridges on carinal denticles and asymmetric posterior carinal denticles; bed 10, Irginian horizon, *clarki* Zone;
 7. DT40-24, partially reduced median ridge, located above the upper surface of the carina; bed 10, Irginian horizon;
 8. Sample 1352-4, lower Buckskin Mt. Fm., Carlin Canyon, NV, USA;
 9. Sample 1352-4, lower Buckskin Mt. Fm., Carlin Canyon, NV, USA.
- 10 – Bed 18 of lower Chihsia Fm. at Tieqiao, provided courtesy of Yadong Sun, referred to as *Sw. whitei*;
 11 – Bed 18 of lower Chihsia Fm. at Tieqiao, provided courtesy of Yadong Sun, holotype.

do not believe that these variations deserve distinction of two separate species as there are many intermediate forms.

Our conclusions, as described above, regarding the morphologic features of the Uralian Early Artinskian *Sw. asymmetricus*, necessitate a revision of the diagnosis of this species; an initial version of this systematic taxonomy is provided below for *Sw. asymmetricus* Sun and Lai emend Henderson.

The synonymy and list of localities provides a correlation of the Artinskian Stage of the Urals with the sections of the same age in the US midcontinent, Canada, and China.

We hope that this taxonomic agreement eliminates the last obstacle for determination of the base-Artinskian GSSP and recommend that a slightly revised proposal be distributed to voting members for a vote as soon as possible.

Systematics

Sweetognathus asymmetricus Sun and Lai **emend Henderson**

Sweetognathus whitei (Rhodes): Chernykh, 2005, p. 148, plate XXIV, fig. 6, 7, 11; Chernykh, 2006, p. 58, plate XIII, fig. 2, 3, plate XIV, fig. 11, plate XV, fig. 4-7; Ritter, 1986, plate 3, figs. 10, 17, 19, 21 (non figs. 11, 16, 18, 20); Ritter, 1987, plate 23.1, fig. 11 (non fig. 3); Wang et al., 1987, figs. 6.16-6.18; Beauchamp and Henderson, 1994, fig. 20.5; Mei et al., 2002, figs. 10.25, 12.2; Sun et al., 2017, plate 1, figs. 2, ?16.

Sweetognathus ‘whitei’ (Rhodes): Read and Nestell, 2018, plate 3, figs. 9-12.

Sweetognathus asymmetricus Sun and Lai: Sun et al., 2017, plate 1, figs. 1 (holotype), 7, 14, 17; Petryshen et al., 2020, fig. 2e.

Diagnosis: A P1 platform element with an elongated rhomboid carina of dumbbell-shaped nodes or transverse ridges with steep margins and pustulose microornament on the upper surface. The transverse ridges are connected by a linear median ridge that consists of a single row of closely spaced and fused pustules. One or two anterior nodes may be asymmetrically distributed with respect to the central pustulose ridge in some specimens, but in other specimens they are symmetric.

Description: The P1 platform element has an ovate basal cup that occupies two-thirds of the unit length. The relatively short free blade in mature specimens bears up to 8 denticles that increase in height anteriorly. The blade merges with the carina. The carina usually consists of 7-9 bilobed (dumbbell-shaped) transverse ridges separated by shallow depressions equal in width to the width of the carinal ridges. Transverse carinal ridges are oriented perpendicular to carinal axis. Ridges joined along the midline of the carina by a row of pustulose microornament. Upper surface of carinal denticles paved with blister-like pustulose microornament. The elongated rhomboid low carina forms a planar surface elevated above the basal cup and is widest at the midpoint. The length of the carina is three-four times greater than its width.

Discussion: The described species differs from *Sw. whitei* (Rhodes) by the presence of flat elongated rhomboidal carina. *Sw. whitei* (Rhodes) has a narrower carina, the transverse ridges of which are separated by v-shaped transverse troughs. Specimens of *Sweetognathus asymmetricus* are similar in appearance to *Sweetognathus whitei*, but in *Sw. asymmetricus*, the transverse ridge carinal denticles are steep margined, regular in form, and pustules are restricted to the top surface of each ridge. Sun et al. (2017) regarded specimens with more symmetrical anterior nodes within the same samples to be *Sw. whitei*, but we view these as part of a population of *Sw. asymmetricus*. Sun et al. (2017) also indicated that *Sw. asymmetricus* differs from the younger *Sw. subsymmetricus* by having a shorter blade, more expanded basal cavity, wider carinal nodes or transverse ridges, and increased spacing of posterior transverse ridges. More taxonomic descriptions of related taxa can be found in the supplementary material of Petryshen et al. (2020).

Occurrence and age: Artinskian Stage, Lower Permian;

the western slope of the South Urals; Riepetown Formation, Moorman Ranch, Nevada; upper Riepe Springs Limestone, Elko County, Nevada; Buckskin Mountain Formation, Carlin Canyon, Nevada; Pequop Formation, Secret Canyon, Nevada; transgressive facies of uppermost Raanes and Great Bear Cape formations, Canadian Arctic (see fig. 10 in Chernykh et al., 2020); lower Ross Creek Formation, southeastern British Columbia, Canada; lower Chihsia Formation (beds 18-23), Tieqiao section, south China.

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Permian substages

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Introduction

The work of the Subcommission on Permian Stratigraphy began in the 1970s and has resulted in current recognition of nine standard Permian stages in three series: Cisuralian Series (Lower Permian)—Asselian, Sakmarian, Artinskian and Kungurian stages; Guadalupian Series (Middle Permian)—Roadian, Wordian and Capitanian stages; and Lopingian (Upper Permian)—Wuchiapingian and Changhsingian stages (Fig. 1). Currently, all but two of these stages (Artinskian and Kungurian) have bases that are defined by GSSPs. Definition of GSSPs for the bases of the Artinskian and Kungurian are close (see the last issue of *Permophiles*), and the SPS is likely a year or less away from having defined a complete Permian chronostratigraphic scale based on the GSSP method.

Realization of this has prompted discussion of what the SPS should focus on in future work. In recent online meetings, the SPS voting and corresponding members have expressed enthusiasm for improving nonmarine Permian chronology and correlations, well exemplified by the work of Schneider et al. (2020). While I fully support this, I also want to advocate another

line of timescale research for the SPS, namely the definition and characterization of substages for the Permian chronostratigraphic scale. Permian substages will provide a much more detailed basis for the subdivision of Permian time than do the nine standard stages.

Shorter chronostratigraphic units should be a goal

One important facet of chronostratigraphic utility often overlooked is the lengths (durations) of chronostratigraphic units. Shorter units provide a more detailed subdivision of time and more refined correlations than do longer units. Thus, the ideal chronostratigraphic unit is a short one that encompasses one or only a few biostratigraphic zones (Lucas, 2013, 2018).

If we use the latest numerical calibration of the Permian chronostratigraphic scale (Henderson et al., 2020), most of the Permian standard stages (Asselian, Roadian, Wordian, Capitanian and Wuchiapingian) are about 5 million years long. The Sakmarian (~3 million years long) and Changhsingian (~2 million years) are shorter, and the Artinskian (~7 million years) and Kungurian (~9 million years) are the longest Permian stages. Subdividing the Permian standard stages into substages, particularly subdividing the longer stages, will provide better temporal resolution to make correlations more precise, and should be one of the next goals of Permian chronostratigraphic research.

Lower Permian substages

I do not advocate any particular Permian substages here, but briefly discuss some of the substages already in use by various workers (Fig. 1). In Russia, the Asselian Stage is divided into three horizons—Sjuranian, Uskalykian and Shikhanian—that correspond to fusulinid zones based on species of *Sphaeroschwagerina*. These are sometimes used as substages, or the Sjuranian and Uskalykian are combined into a Kholodnian substage (e.g., Kotlyar, 2000). To my knowledge, no effort has been made to use these substages outside of the Uralian basin.

Sakmarian has long been divided into two substages—Tastubian and Sterlitamakian—sometime treated as stages (e.g., Furnish 1973). Rauser-Chernousova (1940) introduced Tastubian (for Tastuba Mountain on the Ufa Plateau in Bashkiria) for essentially the zone of the fusulinid “*Schwagerina*” (“*Pseudofusulina*”) moelleri and to mark the LOs (lowest occurrences) of the ammonoids *Metalegoceras* and *Uraloceras*. Rauser-Chernousova (1938) had earlier introduced Sterlitamakian, and Ruzhentsev (1951, 1952, 1955) treated it as a substage of the Sakmarian. In the southern Urals, the base of the Sterlitamakian is marked by the LOs of the fusulinid *Pseudofusulina uralense*, the conodont *Sweetognathus primus* and the ammonoid *Sakmarites inflatus*.

The Artinskian has long been divided into two substages (Ruzhentsev, 1956). The lowest, Aktastinian, was introduced by Ruzhentsev (1934) as the Aktastin horizon and later (Ruzhentsev 1955) treated as a substage. It is named for the Aktasty River in western Kazakhstan. Ruzhentsev (1956) introduced the Baigendzhinian substage for the Baigendzhin region on the border of the Aktyubinsk (now Aktobe) and Orenburg districts of the southern Urals. Studies of Baigendzhinian ammonoids go

back to Verneuil (1845) and Karpinsky (1889), and the LOs of ammonoids such as *Pseudoschistoceras*, *Parapronites*, *Sicanites*, *Atsabites*, *Paraceltites* and *Neocrinites* mark the beginning of the Baigendzhinian. Waterhouse (1976, 1978) used Baigendzhinian (consistently mis-spelled as “Baigendzinian”) as a stage instead of Artinskian to refer to what he called the “classic” Artinskian (i.e., the post-Sakmarian Artinskian of Karpinsky), abandoning the Artinskian as a facies term of varied usage.

The traditional Kungurian included two horizons, the Filippovskian (lower) and Irenian (upper). However, because of the lack of biostratigraphically useful fossils in these horizons, Chuvashov (1994) and subsequent workers have moved the base of the Kungurian down to include what had traditionally been the upper horizon of the Artinskian, the Saranian. The Sarana horizon includes conodonts (particularly *Neostreptognathodus pnevi*) by which the Kungurian base could be defined. Saranian, Filippovskian and Irenian are sometimes treated as substages of the Kungurian.

The Russian Stratigraphic Committee moved the top of the Lower Permian (Cisuralian) Series of the Russian Permian chronostratigraphic scale upward to encompass the entire Ufimian regional stage (Russian Interdepartmental Stratigraphic Committee, 2006; Lozovsky et al., 2009). Thus, the Russian concept of Kungurian in Russia now encompasses five regional substages (ascending order): Saranian, Filippovskian, Irenian, Solikamskian and Sheshmian (the latter two comprise the Ufimian), though some workers regard the Sheshmian as of earliest Guadalupian age.

Lower Permian substages have also been proposed in the North American regional chronostratigraphy. Thus, most American fusulinid biostratigraphers have long divided the Wolfcampian into three substages, lower, middle and upper, also termed Newwellian (or Bursumian), Nealian and Lenoxian (e.g., Thompson, 1954; Dunbar et al., 1960; Wilde, 1990, 2002, 2006).

The Leonard Series (Stage) is based on the Hess Formation, the overlying Cathedral Mountain Formation and lateral equivalents in the Glass Mountains of West Texas. These stratigraphic intervals have provided the basis for fusulinid-based substages, the Hessian and Cathedralian (Ross, 1986; Ross and Ross, 1987), also sometimes used as stages. Thus, Furnish (1973) used Leonardian in a restricted sense, dividing the Leonard Series into Aktastinian (= lower Leonard), Leonardian (= upper Leonard) and Roadian (=Road Canyon Formation) stages. Ross (1986) introduced the Cathedralian Stage to replace Furnish’s (1973) restricted Leonardian Stage, and Ross and Ross (1987) proposed the Hessian Stage to replace Aktastinian, though, if used, Hessian and Cathedralian are generally regarded as substages (Fig. 1).

Middle and Upper Permian substages

The Guadalupian, and its three North American stages (Roadian, Wordian and Capitanian), provide the international chronostratigraphic standard for middle Permian time (Lucas and Shen, 2018). However, to my knowledge no Guadalupian substages have been proposed (Fig. 1). There are substages of the Russian regional chronostratigraphic units correlative to the Guadalupian, the Kazanian and most of the Tatarian, but

they are in nonmarine or evaporitic facies unsuitable for global chronostratigraphic definition.

The base of the Wuchiapingian Stage is defined by the GSSP in the Penglaitan section in southern China that also defines the base of the Lopingian Series. Substages of the Wuchiapingian are Laibinian and Laoshanian, divided by the FAD (first appearance datum) of the conodont *Clarkina leveni* (Jin et al., 1994a, b,

Series	Stage	Substage
Lopingian	Changhsingian	Meishanian Baoqingian
	Wuchiapingian	Laoshanian Laibinian
	Capitanian	
	Wordian	
Guadalupian	Roadian	
	Kungurian	Cathedralian Hessian
		Baigendzhinian
Cisuralian	Artinskian	Aktastinian
	Sakmarian	Sterlitamakian Tastubian Shikhanian Uskalykian Sjuranian
	Asselian	
		GSSP

Fig. 1. The Permian chronostratigraphic scale showing a possible set of Permian substages. Note that no substages of the Guadalupian have been proposed, and not all substages proposed for the Permian are shown here

1998). Substages of the Changhsingian Stage are the Baoqingian and Meishanian. They are divided by the FAD of the conodont *Clarkina changxingensis* (Jin and Shang, 2000).

Prospectus

As the GSSPs of the Permian standard stages are completed, chronostratigraphic research should focus on subdividing the nine stages into substages and defining their boundaries. Substages will provide an even more detailed basis for the subdivision of Permian time than do the stages and should be a goal of further work by the SPS. Indeed, the frontier of Permian chronostratigraphy is in the definition and characterization of substages.

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Permian continental trace fossils of Morocco: first record from the Jebilet massif

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Introduction

The first trace fossils were discovered in the Jebilet massif of south-central Morocco after extensive fieldwork in spring 2019. Two collection campaigns in autumn of the same year

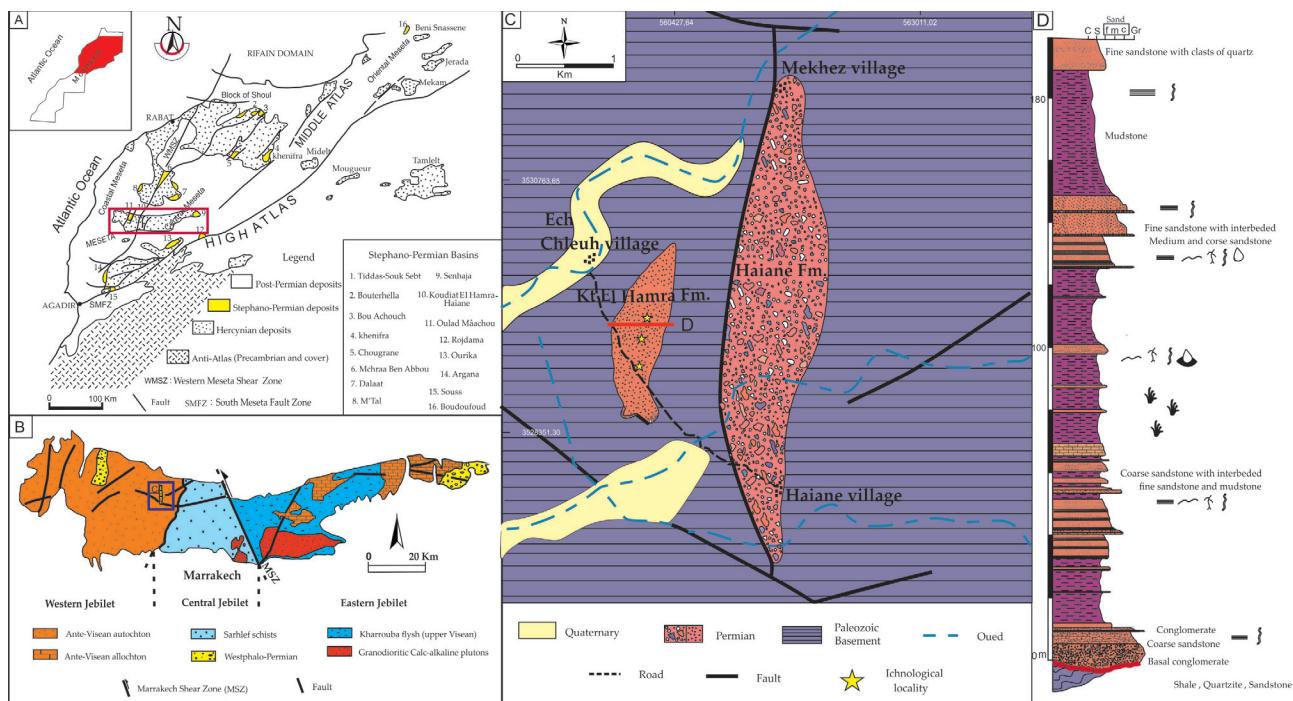


Fig. 1. Geological framework of the Koudiat El Hamra – Haiane Basin. A. position of the study area in south-central Morocco; B. simplified geological map of the Jebilet Massif; C. simplified geological map of the Koudiat El Hamra – Haiane Basin with position of trace fossil localities; D. stratigraphic section of the Koudiat El Hamra Formation.

increased the number of specimens significantly. Our discovery is not only the first record of trace fossils in the Paleozoic of the Koudiat El Hamra-Haiane basin, but also evidence for a Permian age of the fossil-bearing red-beds. This report is intended to shortly highlight the new discovery and its stratigraphic and paleoecological implications for the regional geology (Zouicha et al., 2021, in press). The presented data are another example for the remarkably fast growing record of trace fossils in Paleozoic-Mesozoic continental strata of Morocco since the beginning of systematic exploration on related ichnofossils (Hmich et al., 2006).

Geological setting and material

The continental Koudiat El Hamra – Haiane Basin is situated about 40 km NW of Marrakech at the easternmost extension of the Western Jbel, south-central Morocco (Fig. 1A, B). The Koudiat El Hamra – Haiane Basin consists of two N-S trending sub-basins, Haiane in the east and Koudiat El Hamra in the west. Both sub-basins are closely adjacent but differ significantly in extent, sedimentary infilling, and bedding orientation (Fig. 1C).

The Koudiat El Hamra sub-basin consists of an almost 300 m-thick succession of interbedded carbonatic sandstones and mudstones with conglomerates and limestone as minor components (Fig. 1D). The trace fossils come from eight localities within the Koudiat El Hamra sub-basin. Since these localities are quite close to each other, we represent them only by three stars (Fig. 1C). Invertebrate and vertebrate trace fossils from fine-grained sediments of the Koudiat El Hamra Formation are associated with ripple marks, raindrops, microbially-induced sedimentary structures, mud-cracks, mud-draped plant remains and root traces.

Paleoichnology

Invertebrate trace fossils from the study area are assigned to *Helminthoidichnites tenuis* (Fitch, 1850), *Scyenia gracilis* (White, 1929), *Sphaerapus larvalis* (Hitchcock, 1858), cf. *Spongeliomorpha carlsbergi* (Bromley & Asgaard, 1979) (Fig. 2A-C). Penetrative traces are the dominating invertebrate ichnofossils of the Koudiat El Hamra red-beds. Most of them may belong to *Scyenia gracilis* and cf. *Spongeliomorpha carlsbergi*,

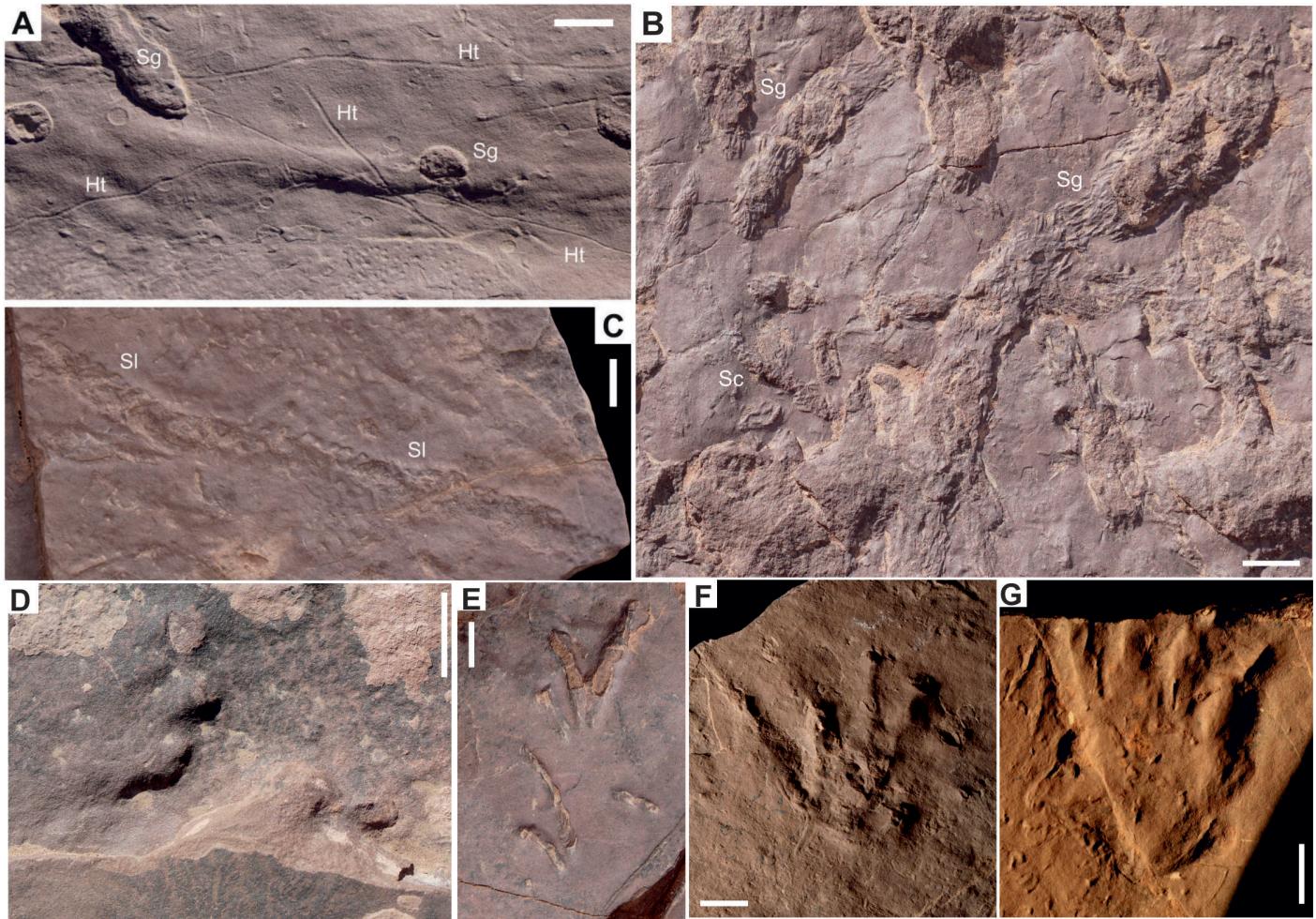


Fig. 2. Trace fossils from the Koudiat El Hamra Formation. A. *Helminthoidichnites tenuis* (Ht), traces preserved beside of scattered raindrop impressions, microbially-induced sediment structures, and burrows of cf. *Scyenia gracilis* (Sg); B. *Scyenia gracilis* (Sg), longitudinally striated burrows of various size and orientation, and a single trace of cf. *Spongeliomorpha carlsbergi* (Sc), short and straight burrow with oblique wall striation; C. *Sphaerapus larvalis* (Sl), single trace preserved in concave hyporelief; D. cf. *Batrachichnus* isp.; E. *Dromopus lacertoides*; F. *Hyloidichnus bifurcatus*; G. cf. *Tambachichnium* isp.

though this cannot be definitely confirmed as ichnotaxonomically significant ornaments are rarely preserved.

Vertebrate traces of the Koudiat El Hamra Formation include tracks assigned to cf. *Batrachichnus* isp. Woodworth, 1900, *Dromopus lacertoides* Geinitz, 1861, *Hyloidichnus bifurcatus* Gilmore, 1927 and cf. *Tambachichnium* isp. Müller, 1954 (Fig. 2D-G). The assemblage is dominated by tracks of *Dromopus* and *Hyloidichnus*, whereas tracks of cf. *Batrachichnus* and cf. *Tambachichnium* are minor components.

Paleoecology and Biostratigraphy

Sedimentological data from the Koudiat El Hamra-Haiane red-beds suggest deposition in a warm climate. A number of sedimentary structures such as ripple marks, raindrops, microbially-induced sedimentary structures and mud-cracks are evidence of repeated alternation between flooding and subaerial exposure.

The tetrapod ichnoassemblage from the Koudiat El Hamra-Haiane basin constrains the age of the fossil-bearing sediments to the late Early Permian (Artinskian) to middle Permian (Capitanian) interval. This represents progress because the red-beds of the study area were hitherto considered to be of Pennsylvanian-Permian age based on lithostratigraphic data only (Huvelin, 1977). Although invertebrate traces are generally not useful biostratigraphic markers, we note that all known occurrences of *Sphaerapus* are younger than the Sakmarian, since

its first occurrence is from the Hermit Shale of Arizona and the uppermost Abo Formation of New Mexico, both interpreted to be of Artinskian age (Lucas et al., 2013; Marchetti et al., 2020; Fig. 3).

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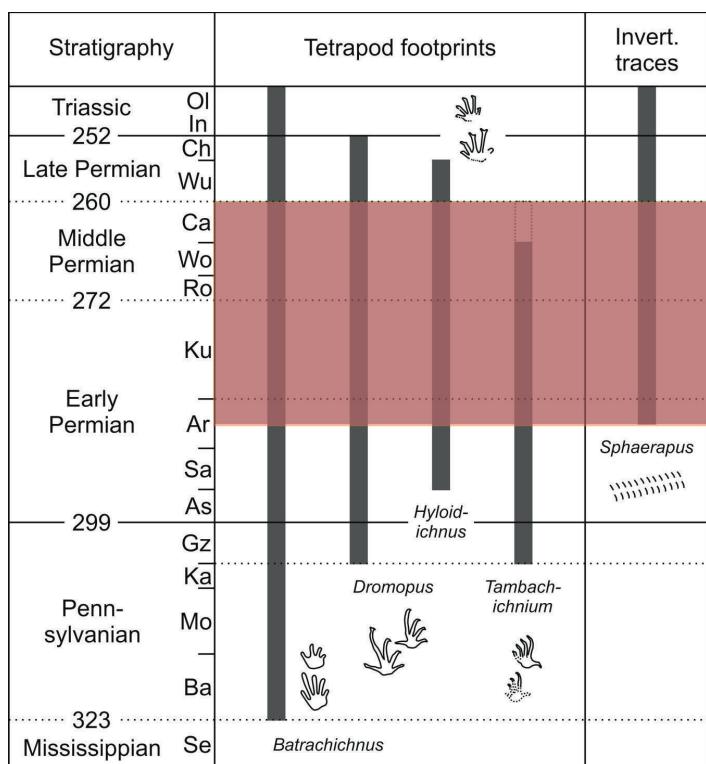


Fig. 3. Global stratigraphic distribution of the ichnotaxa from the Koudiat El Hamra Formation based on Hasiotis (2002), Schlirf (2005), Hminna et al. (2012), Lucas et al. (2013), Voigt and Lucas (2018), Metz (2020), Schneider et al. (2020). The red-colored box refers to the age of the Koudiat El Hamra Formation suggested by the ichnofossils described in this work.

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Tectono-sedimentary evolution of the Upper Paleozoic Mulargia-Escalaplano molassic basin (Sardinia, Italy) in the collapsing Variscan chain: matching the pull-a-part model of the W Europe basins

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Introduction

In Sardinia (Italy) the features of the Mulargia-Escalaplano late to post-Variscan molassic basin have been investigated. After the Variscan orogenesis (Carmignani et al., 1994), in late Pennsylvanian to Permian times, Sardinia was subject to continental sedimentation that took place in scattered basins along major tectonic lines (Carmignani et al., 2001), that possibly were Variscan thrusts surfaces reactivated as transcurrent lines (Ziegler and Stampfli, 2001). These basins (Fig. 1) are related to the collapse of the Variscan chain (Barca et al., 1995;

Carmignani et al., 2001) and have been studied for stratigraphic, sedimentological, and palaeontological aspects (Ronchi et al., 2008, Ronchi et al., 2014, Costamagna, 2019).

Methods

Geological investigations have been undertaken in all the areas where old and newly found outcrops of the Mulargia – Escalaplano Basin can be traced and examined: reconnaissance surveys were implemented to frame them in the correct stratigraphic order (Fig. 1). The description and interpretation of their sedimentary structures, facies, and lithological associations have been carried out for the setting of a depositional model. Particular consideration has been devoted to the reconstruction of the vertical and lateral evolution of the lithofacies in different sectors, and to the relationships between tectonics and sedimentation.



Fig. 1. Localization of the investigated post-Variscan Mulargia-Escalaplano basin in Sardinia

Geological framework

The Upper Pennsylvanian-Permian succession of the Mulargia-Escalaplano molassic basin crops out in the Gerrei area of central Sardinia (Barca et al., 1995; Cassinis et al., 2000; Barca and Costamagna, 2005). The stratigraphy is featured by the lower limnic Rio Su Luda Formation (Ronchi and Falorni, 2004) and by the upper red-bed Mulargia Formation (Costamagna, 2019) (Fig. 2). The sedimentary basin consists of two adjacent sectors: to the NW, the Mulargia sector; to the SE, the Escalaplano sector. They are presently separated by a structural Caenozoic high mainly built of Variscan basement rocks. The Mulargia and Escalaplano sectors of the basin were traditionally considered as separated entities, although the close stratigraphic and sedimentological relationship of the Mulargia and Escalaplano Upper Paleozoic successions was evident for long times (Pecorini, 1974) and suggests considering them as a single basin with only consequential differences in the depositional facies. The Upper Paleozoic succession is unconformably sealed by Triassic (Costamagna et al., 2000) or Eocene (Pertusati et al., 2002) deposits.

Sedimentological and stratigraphic traits

The Rio Su Luda Formation is about 60 m thick and crops out only in the northern area of the NW Mulargia sector: it thins out gradually southeastward until its complete disappearance. It

is formed by usually dark siliciclastic, conglomeratic to pelitic deposits, showing initially a gradually fining-upward trend turning rapidly to a gradually coarsening-upward one. The finest pelitic intermediate deposits are thinly laminated and contain scattered intercalations of graded sandstone beds with erosive base showing groove-casts, tool-casts, and flute casts structures (Fig. 3A). They are also rich in plant remains that support a Stephanian age (Pittau et al., 2008) ("Autuniano sardo" of Ronchi et al., 2008). The top of the unit is featured by meter-thick coarse depositional events referable to subaqueous debris flows (Fig. 3B). The depositional environment of the Rio Su Luda Formation can be referred to as a tectonically active narrow alluvial to palustrine(?) lacustrine basin subject to variable energy in times (Costamagna, 2019) under a wet climate (Pittau et al., 2008).

The coarsest deposits of the Rio Su Luda Formation are followed with erosive, but gradual contact by the Mulargia Formation, a red-bed siliciclastic to volcano-sedimentary unit with scattered carbonate beds. The transition is also marked by a gradual color change from dark grey to red. If there is any significant stratigraphic gap is still unclear. Everywhere but in the northern area of the NW Mulargia sector, the Mulargia Formation rests unconformably over the Variscan metamorphic basement (Fig. 2). At its base, the Mulargia Formation contains pebbles and cobbles deriving from the erosion of the lower Rio Su Luda Formation. The Mulargia Formation thickness varies according to the sector, reaching a maximum of 250 m in the Mulargia sector. Its grain size varies from conglomeratic to pelitic. Also, the Mulargia Formation thins out eastward. It can be subdivided into two fining-upward subcycles, every one of them topped by volcanic deposits of high-K sub-alkaline affinity (Cassinis et al., 2000): they are separated by a weak unconformity marked by a continuous conglomerate level. Radiometric dating reported for this unit an age of about 300 to 295 Ma (Gaggero et al., 2017). Both the Mulargia Formation subcycles show also a directional grain-size fining trend SE-oriented. Sedimentary structures, as cross-bedding and imbrications, support this SE flow direction. The bed shape of the coarsest lithologies changes southeastward from tabular to lenticular (Fig. 3D), as well as their architectural organization, showing growing evidence of lateral accretion in the same direction (Fig. 3C). Thus the fluvial style evolves southeastward from braided towards sinuous channel patterns. Compositional and textural maturity of the siliciclastic deposits grows southeastward likewise. Carbonate deposits, often silicified, are scattered: they are dm-thick beds frequently built of microbialitic mats. Those beds are embedded into reddish pelites: their abundance grows up gradually SE-ward. Here, fossils remain (gastropods, ostracods, Characeae oogons: Pecorini, 1974) are rare. Evaporitic remains are also present in the carbonate beds as quartzose pseudomorphs, as well as streaks and nodules of chert. The age of the Mulargia Formation represents a problem. Despite the reported radiometric age (Gaggero et al., 2017), the presence of Rio Su Luda Formation pebbles into the Mulargia Formation suggests a younger age of this latter unit (Saxonian?). This would agree with the general story of the coeval basins in W Europe. The depositional environment of the Mulargia Formation can be referred to a wider alluvial to playa-lake basin showing evolving lower energy fluvial styles in space

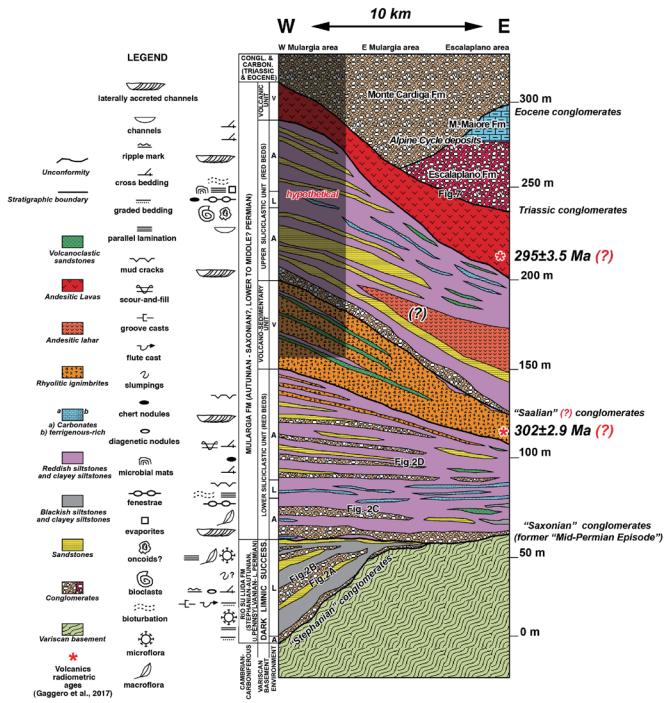


Fig. 2. A 2D - model of the Mulargia-Escalaplano basin showing the NW-SE stratigraphic evolution. Note the E-ward decrease in thickness and mean grain-size of the stratigraphic units, the rapid thinning up to the disappearance of the Rio Su Luda Fm, the growth of carbonate rocks in the same direction, the several unconformities. A: Alluvial environment. L: Lacustrine-palustrine? environment. Radiometric data after Gaggero et al., 2017.

and time, and thus subject to variable energy (Costamagna, 2019) under a dry climate (Pittau et al., 2008): its evolution was punctuated by tectono-magmatic spikes rejuvenating the surrounding landscape.

The coarsest and the finest deposits of both the Rio Su Luda Formation and Mulargia Formation are concentrated close to the NW-most outcrops, as well as the maximum thickness of the investigated stratigraphic units. A gradual decrease of the present dip of the beds from the bottom to the top of the entire succession until a near-horizontal attitude has been detected as well. On the whole, the basin presents a clear NW/SE asymmetry of the filling (Fig. 4).

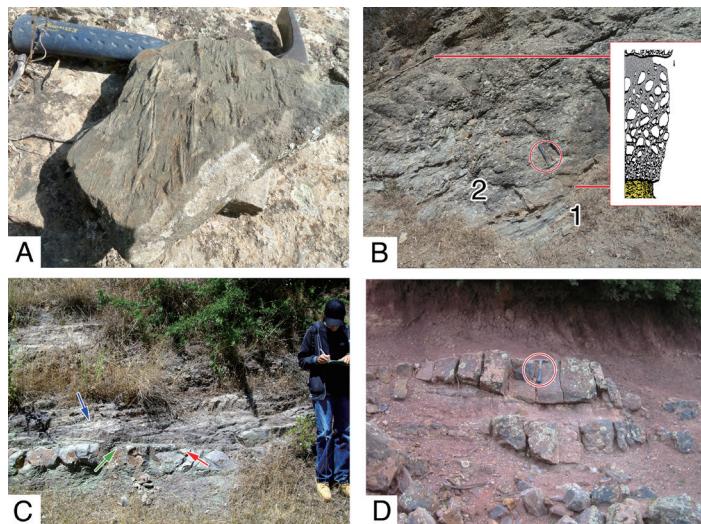


Fig. 3. A. Tool casts and groove casts at the base of a sandstone bed. Hammer = 30 cm. Rio Su Luda Fm, Loc. Genna Ureu; B. Coarse, CU- to FU-graded event (2) over grey sandstones (1). Inset of modeled features of a subaqueous debris flow event from Nemec and Steel, 1984. Rio Su Luda Fm succession, Antoni Cauli N road cut. Hammer = 30 cm. C. Lateral accretion structures (blue arrow) with a thin basal lag (green arrow) over an erosional surface (red arrow) in the. Man height 170 cm. Mulargia Fm, Loc. Su Pitzu de Mataracui. D. Lenticular sandstone bodies with erosive base in the LSU. Hammer 30 cm. Mulargia Fm, Loc. Is Xivas. Stratigraphic location of the pictures in Fig. 2.

Tectonics/sedimentation relationships

Previously Barca et al. (1995) suggested that the Mulargia sector of this sedimentary basin was a Variscan tectonically controlled area. By the strongly direction-bound sedimentary data here presented, we confirm that the facies organization of this entire Late Paleozoic basin was ruled by a NW located, NNW/SSE oriented close listric fault area, the Mulargia Fault zone, formerly evidenced as a Variscan main thrust belt (Funedda et al., 2008, and references therein), which reverted its kinematic behavior during the late Pennsylvanian-Permian collapse of the Variscan chain. The Mulargia Fault zone bounds the W-most outcrops of the basin. According to Christie-Blick and Biddle (1985), the telltales of the pull-a-part basins are A) mismatches across basin margins; B) longitudinal and lateral basin asymmetry; C) episodic rapid subsidence; D) abrupt

lateral facies changes and local unconformities; E) marked contrasts in stratigraphy, facies geometry, and unconformities among different basins in the same region (Fig. 4) (Cassinis et al., 2000; Costamagna, 2019). They all are in good accord with the described sedimentary features of the Mulargia-Escalaplano basin, allowing to set it into this frame (Fig. 4). Besides, Nilsen and Sylvester (1995) emphasize the asymmetric distribution of the sediments in the pull-a-part basins, with both the coarsest and the finer-grained and deeper water deposits accumulating subparallel to and next to the most active strike-slip margin: in our case the coarsest deposits (the debris flow events with cobbles of the Rio Su Luda Formation), and the finest and deepest deposits (the dark pelites of the Rio Su Luda Formation) of the Mulargia-Escalaplano succession, are located westward close to the Mulargia Fault zone. The Mulargia Formation facies organization follows closely the same directional trend, with the highest energy deposits located the closest to the Mulargia Fault zone.

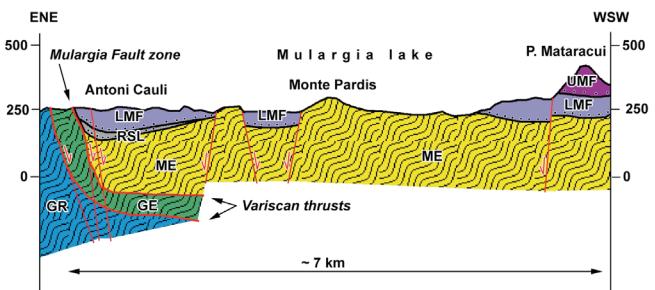


Fig. 4. Interpretative W-E geological sketch of the western-central part of the Mulargia-Escalaplano pull-a-part basin (inspired, redrawn, and modified from Funedda et al., 2008). RSL: Rio Su Luda Fm; LMF: lower Mulargia Fm; UMF: upper Mulargia Fm. Variscan Tectonic Units: GR: Rio Gruppa Tectonic Unit; GE: Gerrei Tectonic Unit; ME: Meana Sardo Tectonic Unit

Results

The Mulargia-Escalaplano molassic basin in central Sardinia preserves a thick succession of continental deposits. Alluvial fan-deltas?, braided and sinuous stream to lacustrine-palustrine?/playa sediments were laid down under wet climates evolving to dryer conditions. Sediments are organized in two superposed main depositional cycles punctuated by recurring volcano-tectonic spikes. In the lower limnic cycle and each of the red bed sub-cycles the depositional energy decreases gradually upwards and southeastward until the onset of the following tectonic phase. Thus cycles and sub-cycles represent erosive responses to tectonic climax producing, in the end, the smoothing of the surrounding relieves: high-energy passing to low-energy continental environments develop gradually in times and show a vertical and lateral evolution towards more sedate depositional processes. The investigated depositional basin is a pull-a-part one related to a main NNW/SSE listric master fault: the sedimentary facies and the stratigraphy are organized accordingly, with strong directional control. Both coarsest deposits and finest and deepest deposits of the basin succession are located close to the NW-located Mulargia Fault zone, representing the master fault. The

basin widens progressively in times and its depocenter shifts gradually SE-wards.

Thus the Mulargia-Escalaplano basin outcrops show a well-exposed example of the evolution of a late to post-Variscan sedimentary pull-a-part basin, successfully comparable with its analogs of SW Europe (Provence, Toutin-Mourin and Bonijoli, 1992; Lòdeve, Lopez et al., 2008; Autun, Pellenard et al., 2017; Saar-Nahe, Schäfer, 2011).

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Latest Carboniferous to Early Permian volcano-stratigraphic evolution in Central Europe: U-Pb CA-ID-TIMS ages of volcanic rocks in the Thuringian Forest Basin (Germany) - summary of the original paper in Int. J. Earth Sci. (Geol. Rundsch.), 2020

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Introduction

In Thuringia, Germany, Upper Carboniferous to Permian deposits are widespread, the major part, however, occurs at subsurface. Only in the Thuringian Forest outcrops range over a wide area. *Permophiles* repeatedly reported on results from this area. We revisited the Thuringian Forest Basin (TFB) with the intention to sample volcanic rocks for high precision age determinations that could help to correlate the basin fill with the International Chronostratigraphic Chart.

Regional and lithostratigraphical setting

The Thuringian Forest Basin (TFB) is situated in a central and important geographic position in the Variscan orogenic belt in the Mid-German Crystalline Rise and the Saxothuringian Zone, and located between Saar-Nahe and Kraichgau Basins in the SW and the Saale Basin in the NE (Fig. 1). The TFB formed during the latest Carboniferous and filled with alternating sedimentary and volcanic rocks under continental environments with a thickness of about 2000 m. Lithostratigraphically, the succession is divided into 9 formations (Fig. 2). The oldest two, Möhrenbach und Georgenthal formations, rest unconformably on the Ruhla Crystalline Complex in the NW, on a deeply weathered granite in the middle part of the Thuringian Forest, and in the SE on folded sedimentary rocks of the Thuringian Slate Mountains with a late Proterozoic up to Early Carboniferous age. The Möhrenbach and the Georgenthal formations are thought to be coeval. Thin sedimentary intercalations within the predominating intermediate volcanic rocks have been used for internal correlation of both formations (Lützner et al., 2012, Andreas, 2014). They reflect a first culmination of volcanic activity, including the overlying Ilmenau Formation which consists of local sedimentary beds alternating with volcanic and pyroclastic rocks of bimodal basaltic and rhyolitic composition. Extrusive volcanic rocks

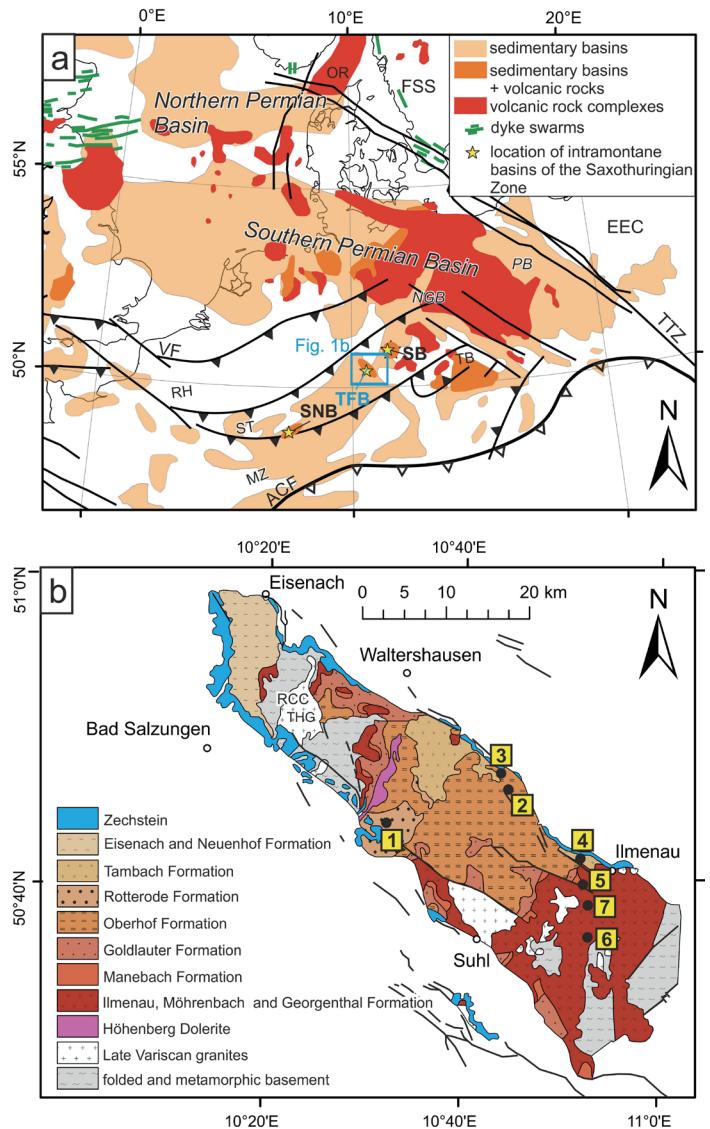


Fig. 1. Simplified geological maps. a) Geological map of the main tectonic elements of Central Europe in relation to the distribution of Upper Carboniferous and Lower Permian sedimentary basins and volcanic rocks (based on McCann et al. 2006 and Mazur et al. 2010). Major tectonic elements are ACF: Alpine-Carpathian front, VF: Variscan deformation front, RH: Rheno-Hercynian Zone, ST: Saxothuringian Zone, MZ: Moldanubian Zone, TB: Tepla-Barrandian Zone, EEC: East European Platform, FSS: Fennoscandian Shield, TTZ: Tornquist-Tisseyre Zone, OR: Oslo Rift. Two sub-basins of the Southern Permian Basin are labelled as NGB: North German Basin, PB: Polish Basin, and the main sedimentary basins of the Saxothuringian Zone are SNB: Saar-Nahe Basin, TFB: Thuringian Forest Basin, SB: Saale Basin. Thick black lines are tectonic elements; thin black lines represent the coastlines of Central Europe. b) Geological Map of the Thuringian Forest Basin. Sample locations for new zircon U-Pb CA-ID-TIMS dating are shown by black circles with sample numbers in yellow boxes. (Lützner et al. 2012, amended). RCC: Ruhla Crystalline Complex, THG – Thüringer Hauptgranit.

are extremely scarce in the subsequent formations, i.e. the coal-bearing Manebach Formation and the fluvial-lacustrine

Goldlauter Formation.

A second culmination of Rotliegend volcanic activity occurred during the deposition of the following Oberhof Formation with an enormous volume of rhyolitic and rhyodacitic volcanic rocks and associated pyroclastics. Periods of lowered activity permitted the development of limited alluvial and lacustrine sedimentary environments that are rich in fossils or organic matter. The volcanic activity continued during the overlying Rotterode Formation with limited and declining volume of volcanic production at the surface. However, a considerable amount of magma was trapped in a rhyolite intrusion and the finally intruded Höhenberg dolerite during the Rotterode/Oberhof gap or during early Rotterode time. Rotterode sediments exclusively consist of red beds, mainly fluvial sandstones and conglomerates that indicate an uprise of the Ruhla Crystalline Complex.

The Tambach Formation starts with coarse conglomerates that covered an eroded paleolandscapes. Locally, deep canyons cut into Oberhof rhyolites filled up with Lower Tambach debris flows (Lützner, 1982) and graded upwards into sandstones and mudstones with the famous Bromacker fossiliferous horizon, well-known for tetrapod footprints and skeletal remains of terrestrial amphibians and reptiles.

The Eisenach Formation occurs at the West flank of the Ruhla Crystalline Complex. Marginal alluvial fans interfingered with sandy mudstones which can be traced to the west below the Zechstein and Triassic by numerous boreholes. The partly haloturbidic mudstones are devoid of fossils.

The Neuenhof Formation is the uppermost Permian formation still with the appearance of Rotliegend red beds. It consists of a 5-10 m thick alternation with fine gravels, sandstones and siltstones of mainly fluvial environment. Magnetostratigraphically, the Neuenhof Formation belongs to the Permian-Triassic Mixed Superchron, whereas all Permian formations mentioned before are part of the Kiaman Reversed superchron (Menning et al., 1986).

Outstanding fossiliferous horizons in the TFB, which are important for basic research in paleontology and biostratigraphy, are marked in Fig. 2 by the letters A to J. Fundamental progress has been obtained during the last decades in paleontology in respect to define biozones of selected fossil assemblages, to trace phylogenetic lineages and finally to correlate timelines through separated basins. Schneider et al. (2020) recently summarized the state of art in biostratigraphic correlation of the Upper Carboniferous and Permian continental basins.

One or two samples were collected from each formation that contain volcanic rocks (for details cp. original paper). We preferred to sample acidic rocks with medium- to large-sized phenocrysts of quartz and feldspar because these rocks generally yielded sufficient zircon crystals.

High-precision U-Pb CA-ID-TIMS method

Recent development in ID-TIMS dating substantially reduced the analytical error of zircon dating, especially through the application of chemical abrasion (CA) on single zircon grains prior to their analysis. In addition, due to efforts of the EARTHTIME initiative (<http://www.earthtimetestsite.com/>), the inter-laboratory bias of zircon ages has been reduced to

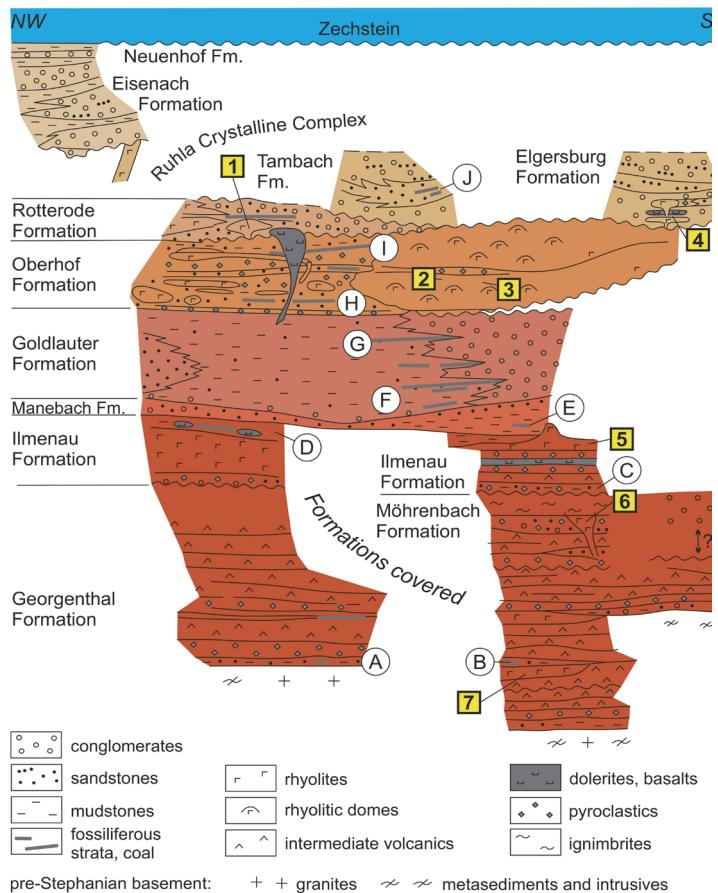


Fig. 2. Lithostratigraphic subdivision of the Carboniferous-Permian sediments of the Thuringian Forest Basin, presented as a schematic NW-SE cross-section. Circled letters label biostratigraphically important fossiliferous horizons: A. Öhrenkammer Horizon (Georgenthal Fm.), B. Ilmtal Horizon (Möhrenbach Fm.), C. Lindenberg Horizon (base of Ilmenau Fm.), D. Sembachtal Horizon (top of Ilmenau Fm.), E. Manebach fossiliferous horizons (Manebach Fm.), F. Sperbersbach Horizon (lower Goldlauter Fm.), G. Gottlob Horizon (upper Goldlauter Fm.), H. Lochbrunnen Horizon (lower Oberhof Fm.), I. Wintersbrunn Horizon (upper Oberhof Fm.), J. Bromacker Horizon (Tambach Fm.). Numbers in yellow boxes represent new sample locations for zircon U-Pb CA-ID-TIMS dating.

0.1% through the use of precisely and accurately calibrated tracers (Condon et al., 2015) and the standardization of raw data correction by the development and supply of open source programs (McLean et al., 2015). As a result, the accuracy and external reproducibility of zircon ages from participating laboratories can be $\leq 0.1\%$ and can be proved by their reported international zircon standard ages. U-Pb CA-ID-TIMS dating was performed in the TIMS lab at the TU Bergakademie Freiberg (Germany). In the original paper (<https://doi.org/10.1007/s00531-020-01957-y>) we provide our ages for the international standards 91500 and Temora 2. We use the error expressed as z that also includes the error in tracer calibration and that of the decay constant. This allows us to compare our ages to those obtained with other tracers and other dating systems.

Results and discussion

Samples 7 and 6 yielded identical (within errors) $^{206}\text{Pb}/^{238}\text{U}$ mean ages (299.7 ± 0.4 Ma vs. 300.0 ± 0.5 Ma) representing the age of the Möhrenbach Formation. Consequently, the Möhrenbach Formation was deposited during the latest Carboniferous, i.e., the Gzhelian (Standard Global Chronostratigraphic Scale) or Stephanian (West European regional scale). Our new age of the Ilmenau Formation (sample 5) is the first precise depositional age for this unit. The sample dates the Kickelhahn Rhyolite near Manebach to 299.3 ± 0.3 Ma. This age overlaps with the recorded age of the Carboniferous–Permian boundary (298.90 ± 0.15 Ma; International Chronostratigraphic Chart 2019/05; the age was obtained by the same U–Pb CA-ID-TIMS method using the 535 spike; Ramezani et al., 2007). Thus, the age of the Kickelhahn Rhyolite provides important information for the stratigraphic position of the C–P boundary in the Thuringian Forest Basin, which has long been discussed as not exactly known.

The Kickelhahn Rhyolite (near Manebach village) is only covered by 10–15 m of tuffaceous conglomerates, above which the Manebach Formation begins with grey fluviatile sandstones. Considering the low thickness of post-rhyolitic volcanoclastic sedimentation, we estimate that the C–P boundary should be positioned approximately at the boundary between the Ilmenau and Manebach formations (cp. Fig. 3).

Our new data suggest an age difference of about 2.5 Myr between sample 5 and sample 3. During this time, the Manebach and Goldlauter formations filled a pull-apart basin with paludal, lacustrine, fluvial, and alluvial sediments. The maximum thickness of both formations is nearly 1000 m, i.e., the rate of subsidence (uncorrected) corresponds to about 400 m/Myr.

Samples 3 and 2 (Oberhof Formation) reflect the culmination of the second volcanic phase within the TFB, which occurred in the range between 296 and 297 Ma. The age of the Komberg Rhyolite intrusion is provided by sample 1 and dates the red beds of the Rotterode Formation. As this formation clearly overlies the Oberhof Formation, the youngest zircon age of this sample (295.8 ± 0.4 Ma) is in agreement with the stratigraphy.

Sample 4 (Wolfstein Rhyolite) was dated with the idea of determining a representative age for the Elgersburg Formation. However, the obtained age is much older than expected, similar to that of the Möhrenbach Formation. The Wolfstein Rhyolite is directly bordered by the Schöffenhaus fault that dislocates the Elgersburg Formation against members of the Ilmenau Formation and the Oberhof or (in question) Rotterode formations. Thus, we suggest that the Wolfstein Rhyolite could be interpreted as a small, tectonically uplifted block.

The new zircon data for the profile of Carboniferous–Permian volcanic rocks in the TFB show older ages compared to the previously published age data (Fig. 3). This reflects the fact that the pre-treatment of the dated zircons by CA removed those components that suffered severe Pb loss.

In general, the new zircon ages (single zircon ages as well as mean sample ages) show less age scatter than those of earlier publications. Consequently, the total duration of the volcanic activity in the TFB was considerably shorter. Whereas previously an age interval between 295 and 275 Ma was expected for the interval between the Möhrenbach Formation and the Elgersburg

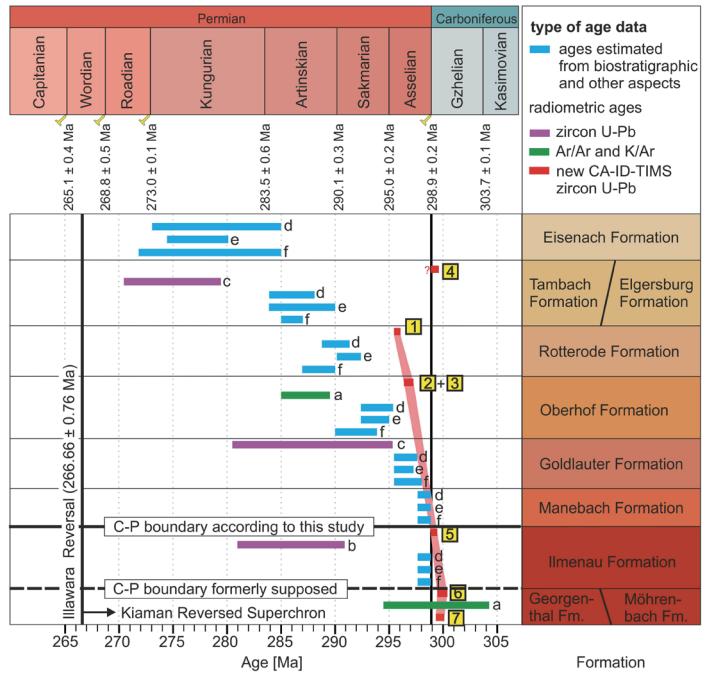


Fig. 3. Compilation of age data from the Rotliegend section of the Thuringian Forest. Radiometric age data are from a: Goll and Lippolt (2001), b: Zeh and Brätz (2000), c: Lützner et al. (2007). The blue bars show the tentative assessment of the Thuringian Forest formations to the International Stratigraphic Chart 2019 after d: Schneider and Werneburg (2012), e: Menning et al. (2016; explanatory notes in Gebhardt et al. 2018) and f: Schneider et al. (2020). Our new CA-ID-TIMS ages are shown in red. Numbers in yellow boxes are sample numbers for new zircon U-Pb CA-ID-TIMS dating. Most of the previous age data and assessments are remarkably younger than the new zircon ages.

Formation (Lützner et al., 2007), our new data suggest a range between ca. 300 Ma for the Möhrenbach Formation and ca. 296 Ma for the Rotterode Formation. Even if the age of the youngest rhyolite (Elgersburg) has not yet been determined, the total duration of volcanic activity has to be reduced from ca. 20 Myr to ca. 4 Myr. The sedimentary gap up to the Illawarra Reversal (ca. 265 Ma after Isozaki, 2009; 266.66 ± 0.76 Ma after Hounslow and Balabanov, 2018) therefore has to be extended to > 25 Myr. This result requires a new view on the early evolution of the Thuringian Forest Basin. The sedimentary hiatus, which can extend locally to 30 Myr in Northern Germany (e.g., between Permian volcanics and the Wustrow Member as the oldest Permian sediment), is at least partially caused by volcano-topographic features (morphology) besides intrabasinal tectonics according to Geißler et al. (2008). Further work is required to evaluate this hiatus in sedimentation for the TFB region as well.

The modern state of biostratigraphy in the continental basins of Pangea has been summarized by Schneider et al. (2020). In the TFB, biostratigraphy is well investigated in the sedimentary record, particularly since Schneider and Werneburg (2012 and papers cited therein) started their work on biostratigraphic zoning in this region. The correlation of zircon ages and biostratigraphic data in continental Carboniferous and Permian basins is partially problematic (e.g., Schneider et al., 2020).

Comparison of Schneider et al. (2020; their Figure 2) with our new age data for the formations near the Carboniferous–Permian boundary (Möhrenbach Fm. plus Ilmenau Fm. = Gehren subgroup) indicates that both datasets are compatible. However, contradictory interpretations are obtained for the Oberhof and Rotterode formations: according to our new ages, both formations originated during the Asselian Stage while Schneider et al. (2020) placed the Oberhof Formation in the Sakmarian and the Rotterode Formation in the Artinskian Stage.

An important amphibian biozone occurs in the uppermost part of the Oberhof Formation (amphibian zone 7 in Schneider et al., 2020) termed the *Melanerpeton pusillum*–*Melanerpeton gracile* assemblage zone, found in the Wintersbrunn fossiliferous horizon [syn. Upper Protriton Horizon (letter I in Fig. 2)]. The evidence of this biozone is widespread. It is reported from the Niederhäslich Formation (Döhlen Basin, Saxony), the Schöneck Formation (Hessian Basins), the Humberg Horizon (top of Meisenheim Formation, Saar–Nahe Basin), from several French basins and from the Olevčín Member (Broumov Formation, Intrasudetic Basin) as well. In the Intrasudetic Basin, this biozone is found in the Ruprechtice limestone horizon in the middle part of the Olevčín Member. Below, at the top of the Nowaruda Member, there occurs the Vraní hory Rhyolite, which is dated by the CA-ID–TIMS U–Pb method at 297.1 ± 0.3 Ma (Opluštíl et al. 2016). This is in good agreement with samples 2 and 3 from the Oberhof Formation and sample 1 from the Rotterode Formation of the TFB. Approximately, 70 m of clastic deposits were accumulated between the Vraní hory Rhyolite and the Ruprechtice Horizon. The amphibian zone 7 is situated in an intermediate position between the uppermost Older Rhyolite of the Oberhof Formation, represented by samples 2 and 3 and the Komberg Rhyolite of the Rotterode Formation (sample 1). Hence, the age of this biozone can be estimated at about 296 Ma from our data.

Conclusions

We report the first investigation by the U–Pb CA–ID–TIMS method of a Stephanian to Lower Permian (lower Rotliegend) profile in the Thuringian Forest Basin. We draw the following conclusions.

1. First, the results fulfill the expectation that the ages change in the same order as the lithostratigraphic sequence.

2. New geochronological results for the Ilmenau Formation (sample 5) and the Oberhof Formation (samples 2 and 3) indicate an age difference of 2.5 Myr between both formations, indicating a ca. 2.5 Myr nearly quiescent magmatic period for the predominantly sedimentary Manebach and Goldlauter formations. This is in accordance with different biostratigraphic zones. However, still-existing discrepancies between biostratigraphy and geochronology have to be resolved by further geochronological dating and additional paleobiological data.

3. The zircon ages of sample 5 (Kickelhahn Rhyolite, Ilmenau Formation) and the two rhyolite samples (samples 6 and 7, Möhrenbach Formation) are very close to the internationally valid chronostratigraphic Carboniferous–Permian boundary (International Chronostratigraphic Chart 2019) at 298.90 ± 0.15 Ma. Based on the new Kickelhahn Rhyolite zircon age, we assume that the position of the C–P boundary should be located

at the base of the Manebach Formation. Thus, the position of the C–P boundary in the TFB can be established more precisely compared to previous estimates.

4. Compared to earlier concepts, the new zircon ages indicate that the total duration of the volcanic activity in the TFB was considerably shorter. Whereas previously an age interval between 295 and 275 Ma was expected for the whole volcanic period in the TFB, now the range is reduced to a period from ca. 300 Ma (Möhrenbach Formation) to ca. 296 Ma (Rotterode Formation). The total duration of volcanic activity is shortened from ca. 20 Myr to ca. 4 Myr.

5. Consequently, the possible time span from the early Permian volcanic rocks (top Rotterode Formation) up to the Illawarra Reversal has to be extended to ca. 30 Myr. This stratigraphic interval can cover 25–30 Myr in parts of the external Variscides.

6. Our newly obtained ages of the dated TFB formations that contain important biostratigraphic fossils can be used as time marks for certain biostratigraphic zones in other continental Late Carboniferous–Early Permian basins.

7. In the future, the chronostratigraphic sequence in the Thuringian Forest could be even more precisely defined by dating the Inselsberg and/or Heuberg Rhyolite as a mark for the base of the Oberhof Formation, and the Elgersburg Rhyolite as a mark for the youngest rhyolite. In addition, new age data from the other continental basins are urgently needed, in particular from the Saar–Nahe Basin, the Saale Basin near Halle and the Chemnitz Basin. Such new data will allow the definition of volcanic–subvolcanic–plutonic complexes as cogenetic systems and the assessment of their geochemical signatures, thermal history, and magmatic–hydrothermal evolution in an integrated way.

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- ## Guadalupian and Lopingian transgression of the Khuff Formation carbonate sea in the Middle East and Levant
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- Recent work on the palynology of the Permian rocks of the Saad and Arqov formations in boreholes in the Negev desert of Israel and the Umm Irna Formation of Jordan (in preparation; Stephenson and Korngreen, 2020), and the sedimentological character of these deposits, has allowed close comparison with the Permian elsewhere in the Middle East, for example the Arabian Peninsula. These comparisons allow a possible subdivision of the Oman and Saudi Arabia Palynological Zone 6 (OSPZ6) using the first uphole appearance of the distinctive multi-taeniate bisaccate pollen *Protohaploxylinus uttingii*, and the tri-sulcate pollen *Pretricolpipollenites bharadwajii*. The comparison also establishes many similarities between the Lopingian tectono-sedimentary evolution of the successions of the Levant and Arabian Peninsula. Amongst other findings, this confirms that the major marine transgression that formed the Khuff Formation and which brought widespread carbonate depositional conditions across the northern Gondwana Tethys margin, was markedly diachronous.
- The Guadalupian to Lower Triassic Khuff Formation represents a major transgressive-regressive cycle deposited along the northern Gondwanan margin across the Arabian Peninsula, Iran (where it is known as the Dalan Formation), and Iraq (Chia Zairi Formation). Palynomorphs are rarely recovered from the Khuff Formation itself in core or outcrops, due to inimical preservation conditions in limestone, and modern desert weathering. However, the basal Khuff Formation siliciclastic beds (BKS), part of the genetic package of the Khuff Formation (Osterloff et al., 2004) yield palynomorphs from both the subsurface and at outcrop. The beds are known across the Arabian Peninsula for their unusually well-preserved plant fossils, for example in Oman the ‘Gharif Palaeoflora’ (Broutin et al., 1995), and in Saudi Arabia the ‘Unayzah Plant Beds’ (El-Khayal and Wagner, 1985). The Jordanian Umm Irna Plant Beds (Kerp et al., 2006) are considered taxonomically, taphonomically and palaeoenvironmentally to be related to the ‘Gharif Palaeoflora’ and ‘Unayzah Plant Beds’.
- Stephenson and Powell (2013) considered that the Umm Irna

Formation showed closely similar fluvial and paralic depositional environments to those described for the upper Gharif Formation alluvial plain ‘Type Environment P2’ in the subsurface in Oman (Osterloff et al., 2004) and the basal Khuff Formation siliciclastic beds at outcrop and in the subsurface in Central Saudi Arabia, and also remarked on their lithological similarity with the Arqov and Umm Irna formations. However, evidence from the palynology of the Umm Irna Formation, Avdat-1 borehole and now the Makhtesh Qatan-2, Ramon-1 and Boquer-1 boreholes (paper in preparation) indicate markedly younger taxa characterise possible BKSB-equivalent beds in the Levant (Fig. 1).

The diachronous onset of the basal Khuff Formation siliciclastic beds which have similar lithological, sedimentological and taphonomic characteristics, but apparently progressively younger palynomorph taxa, appears to occur northwest through the Arabian Plate (Fig. 1) over an extended period of around 15 my, from the early Wordian (base ~269 My) to the Changhsingian (base ~254 My). The BKSB may indicate a period of humid high runoff producing river systems draining previously drier hinterlands, that heralded the transgression that brought on the main Khuff Formation carbonate sedimentation that in parts of the Middle East persisted for 20 My.

Angiolini et al. (2003) interpreted the Khuff Formation

to record a major transgression of Neotethyan waters in the Wordian, at a stage of full oceanization and tectonic quiescence, when thermal subsidence caused final drowning of rift shoulders and deposition of marine carbonates onto vast portions of stable Arabia.. They concluded that similar transgressive trends took place during the Wordian in the Himalayas, Tunisia, and the Salt Range of Pakistan. However, our preliminary findings relating to diachronism northwest along the Neotethys shore may indicate either slower thermal subsidence or less thermal subsidence in central Arabia and the Levant since this was transgressed later. It may also indicate the influence of persistent ‘Hercynian’ structures/highs such as the central Arabian arch, or in the Levant, the Helez Geanticline (Gvirtzman and Weissbrod, 1984), or the influence of the Arabian Nubian Shield.

Further studies are required to understand the reason for the strongly diachronous base of the Khuff Formation and its equivalents. Comparison with similar tectono-stratigraphic events elsewhere in the Phanerozoic may also provide insights.

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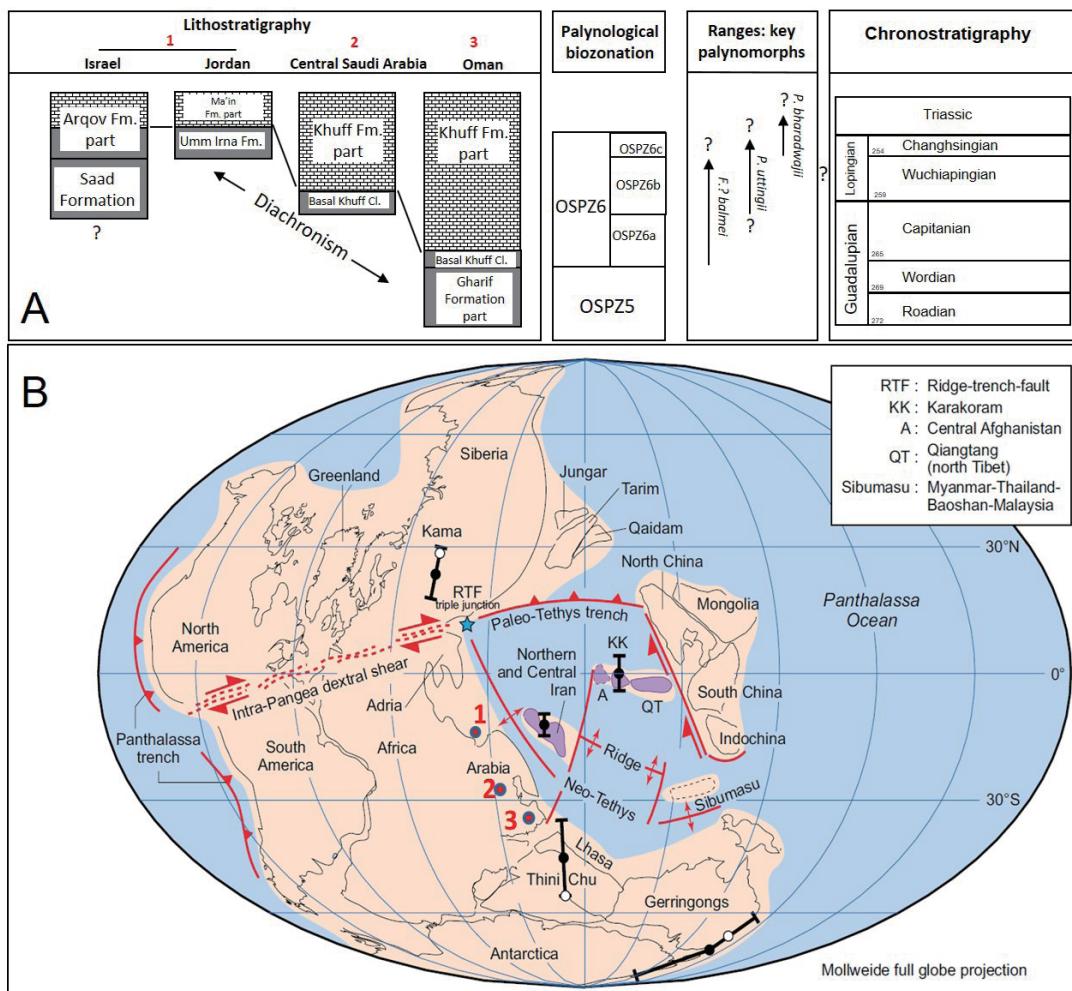


Fig. 1. (A) Stratigraphic distribution of OSPZ5 and proposed subdivisions of OSPZ6 (a, b, and c). (B) Middle Permian continental configuration. 1. Jordan/Israel ; 2. Saudi Arabia; 3. Oman. (map modified after Muttoni et al. 2009)

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One step closer to understanding the Permian-Triassic mass extinction

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Last October Jurikova et al. (2020) published a new paper that illuminates the causes and consequences of the events that resulted in Earth's largest mass extinction. Here, I summarise the key findings and discuss their implications.

The last few decades have seen many exciting developments in palaeontology, geology, geochemistry, and geochronology which have significantly progressed our understanding of the

Permian-Triassic mass extinction (and much of Earth's intriguing history). New evidence emerged suggesting factors as dramatic increase in sea surface temperatures, widespread anoxia and even euxinia, or ocean acidification to have played an important role in the extinction. But how do these different environmental stressors come together in a bigger picture, and fundamentally, what was their underlaying trigger?

Naturally, magmatism from the large igneous province Siberian Traps lends itself as the most likely trigger candidate due to being contemporaneous with the extinction, and the fact that we actually do have a direct evidence for it (unlike gas hydrates or bolide impact). Mantle as a source of isotopically light carbon (considering a value of about –6 ‰) in principle could qualify as a potential cause of the well-known global negative carbon isotope excursion characteristic of the extinction, at least unless latest chronologies are considered. Assuming that the duration of the extinction was on the order of few thousands to ten thousands of years (Burgess et al., 2014), then the mass balance falls out with geologic evidence. In other words, there is no reasonable way a mantle source could explain the sharp carbon isotope excursion; we would need a much larger province or a much lighter source (and this is where gas hydrates which isotopic composition is around –30‰ for biogenic to –60‰ for thermogenic methane offer a convenient hypothesis). So how can we reconcile this issue?

We set out to explore these questions using a novel geochemical approach – the boron isotope pH-proxy. The knowledge of seawater pH on its own is a critical parameter; it is of great relevance to marine life, but most importantly because ocean pH and atmospheric CO₂ are closely coupled, it allows for the reconstruction of the latter. The pre-requisite for a robust pH and CO₂ reconstruction from boron isotopes is a well-preserved and well-calibrated “archive”, specifically a skeletal component of a marine calcifying organism (for obvious reasons this makes boron-based reconstructions over mass extinction intervals rather challenging). Using brachiopods from the Southern Alps in Italy and few specimens for comparison from South China, we reconstructed seawater pH over the onset of the extinction (I am indebted to Lucia Angiolini, Renato Posenato and Uwe Brand who entrusted a starting PhD their precious brachiopod fossils for what was at the beginning a rather experimental adventure). We paired our pH data with global carbon isotope records, and assimilated it into an innovative geochemical modelling framework that simulated the carbon cycle as well as redox-resolving biogeochemistry and nitrogen isotope turnover in the oceans.

In the first place, we quantified the source and volume of CO₂ emissions required to match the carbon isotope and pH constraints. Our results showed that a large pulse of CO₂ was released into the atmosphere reflecting the metamorphic degassing of organic carbon during volcanic intrusions into coal basin sediments. Our estimated total emissions amounted to approximately 106,000 Pg C or 388,000 Pg CO₂ over the duration of the extinction (with carbon isotope composition of predominantly –18‰). To put it in perspective, this is more than 40 times the amount of carbon available in modern fossil fuel reserves, including that already burned since the industrial

revolution, and likely the biggest single event of carbon release during the Phanerozoic. The volcanism lasted for millions of years; it was however first when the intruded magma heated the organic-rich sediments that resulted in the sudden and steep CO₂ release that triggered the extinction!

In the second place, we studied the impact of the CO₂ release on the marine environment and global biogeochemical cycles (Fig. 1). Running numerous sensitivity and model tests to envelope the boundary conditions, we created a scenario that effectively combined available geochemical, geological and palaeontological records to explain the course of the extinction. Our results showed that the large CO₂ pulse led to a strong greenhouse effect on the environment, causing severe heating and acidification of the ocean, which would have provoked the preferential early disappearance of shallow-water and reef-building taxa. An important consequence of the high atmospheric CO₂ levels and hot temperatures in our model was a dramatic increase in chemical weathering rates on land, which led to an elevated flux of nutrients to the ocean affecting the marine biological pump. Warm temperatures and new nutrients supported elevated primary production, which on one hand side aided the drawdown of atmospheric CO₂, but on the other resulted in greater respiration at depth. This led to the decline of oxygen and accumulation of dissolved sulphide in the waters, and would have contributed to the later disappearance of many deeper-dwelling species and remaining benthos. Deoxygenation of the oceans also

holds the key for the persistence of the marine crisis throughout much of Early Triassic. Under low oxygen conditions, ammonium, phosphate and iron were released from seabed sediments and supported the rise in export production and respiration in a strong positive feedback loop, delaying the recovery of the marine redox state.

I dare not to say that this provides the ultimate answer for the mass extinction, quite the opposite, I think it raises interesting questions which I hope will inspire future research and contribute new ideas (indeed this seems to have been the case and I gratefully acknowledge the many comments and interesting debates that followed the publication of the article), but in the meantime I believe it offers a compelling scenario that brings together many pieces of the Permian-Triassic mass extinction puzzle.

I have dedicated a large part of my work over the past years to improving our understanding of brachiopod geochemistry and biomineralisation (Jurikova et al., 2019; 2020), and more recently in particular to pushing the boundaries of trace element and boron isotope analyses; we can now go smaller (sub-mg calcite sample size for most cases), more precise (<0.2 ‰ for δ¹¹B) and most importantly reach higher sample throughput than ever before. While this has greatly reduced what has traditionally been the biggest bottleneck to geochemical proxy-based palaeoenvironmental and palaeo-climatic reconstructions, paradoxically, it has also created a new one. I am now constantly on the



Figure 1. Artist's reconstruction of the onset of the Permian-Triassic mass extinction based on Jurikova et al. 2020. Illustrated by Dawid Adam Iurino (PaleoFactory, Sapienza University of Rome).

search of new well-preserved Permian-Triassic (but not only) brachiopods and would warmly welcome new collaborations and opportunities to access and/or collect new material.

This work would not have been possible without the incessant support of all the co-authors and the funding from European Union's Horizon 2020 programme (grant agreement no. 643084, "BASELiNE-Earth").

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Report of fieldtrip to northern Tibet: Permian successions in blocks of the Qingshai-Tibet Plateau

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Introduction

It has been widely acknowledged that the Qingshai-Tibet Plateau played an important role in the process of rifting of the Cimmerian continents during the Permian Period. The strata

together with pronounced marine paleobiogeography during the Permian are significant in reconstruction of the paleogeography.

Supported by the Second Tibetan Plateau Scientific Expedition and Research Programme and other programs, a team of 25 people (including researchers, reporters, drivers and chef) conducted a 29-day field expedition to several localities in northern Tibet from 9th September to 3rd October, 2020 (Fig. 1). The goals of this fieldtrip include: (1) to explore the origin of exotic limestone blocks within the Bangong-Nujiang suture zone; (2) to understand the transition from Permian to Triassic in the North Qiangtang Block; (3) to explore the composition of the accretionary complex within the Longmu Co-Shuanghu suture zone and (4) to study the depositional processes of glacio-marine siliciclastic deposits and warm-water carbonates in the Lhasa Block. Here, we will report the preliminary findings of the fieldwork.

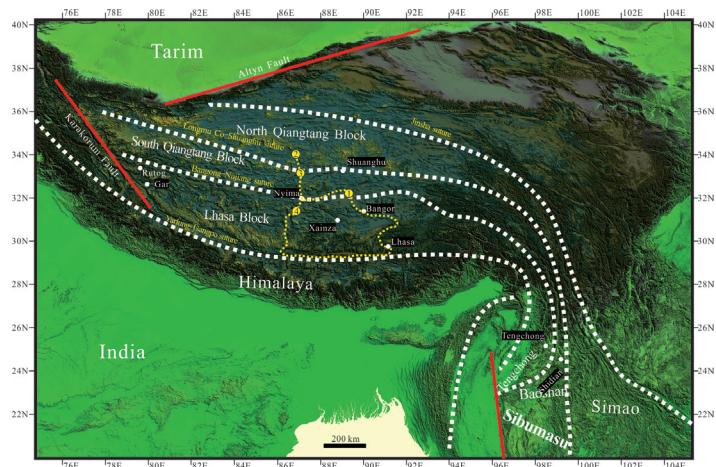


Fig. 1. The field route and study sites in the northern Tibet.
① Duomar area; ② Raggyorcaka area; ③ Rongma area; ④ Wenbu area

First locality: Duomar Town, Shuanghu County

The opening mechanism of the Neotethys Ocean is a key scientific problem that has not been resolved. Some scholars argued that the southward subduction of the Mesotethys (Bangong-Nujiang) Ocean triggered the formation of the Neotethys Ocean to the south of the Lhasa Block (e.g., Zhu et al., 2013). However, so far there is not enough evidence to support a southward subduction. Within the Bangong-Nujiang suture zone, there is a set of Mesozoic accretionary complexes, namely the Mugagangri Group (Wen, 1979). Numerous detrital zircon studies have proved that this group originated from the South Qiangtang Block in the north (Sun et al., 2019; Ma et al., 2020). Interestingly, there are numerous Permian exotic limestone blocks within the accretionary complex (Fig. 2A). The purpose of our fieldwork in this region was to explore the origin of the Permian limestone blocks. If the limestone blocks came from the Lhasa Block, we can suggest that the Bangong-Nujiang Ocean subducted toward north rather than south.

We found that most limestone blocks had been subjected to strong recrystallization, which hampered the preservation of fossils. The most common fossils found in the limestones are sponges and calcareous algae (Fig. 2B). Fortunately, we found a limestone block with relatively weaker recrystallization to the

south of Duoma Town. Within this limestone block, we found diverse fusulines. The fusulines are now being processed in the laboratory.



Fig. 2. Field views in the Duoma area, Shuanghu County
A, Permian limestone blocks within the Mugagangri Group; B, Permian limestone with sponges and calcareous algae

Second locality: Raggyorcaka area, Nyima County

The Raggyorcaka area belongs to the North Qiangtang Block based on the typical warm-water biota across the Carboniferous-Permian transition (Zhang et al., 2016). The Permian and Triassic strata are widely exposed in this region. Previously, the Permian strata were named as the Raggyorcaka Formation, which is characterized by mudstones and shales with sandstone and limestone interbeds (Wen et al., 1979). Abundant fusulines such as *Palaeofusulina nana*, *P. sinensis*, and *P. fusiformis* were discovered in the limestone, suggesting a Changhsingian Age (Wang et al., 1981). In our fieldwork, we found a thick succession of limestones about 100 meters below the Raggyorcaka Formation (Fig. 3A). This unit has been named the Xueyuanhe Formation by the Institute of Geological Survey of Jilin University (2005). According to the original definition, the age of the Xueyuanhe Formation was assigned to the Middle Permian. However, in the fieldwork, we preliminary confirmed the presence of the foraminifera *Colaniella*, suggesting a Late Permian age for this limestone interval. Consequently, the transition from the limestones of the Xueyuanhe Formation to the siliciclastic successions of the Raggyorcaka Formation represents a regression event. The sea-level variations continued in the Raggyorcaka Formation and resulted in the frequent occurrence of many limestone interlayers within the mudstones. Abundant fusulines such as *Palaeofusulina* and the brachiopod *Leptodus* were found in the limestone interlayers (Fig. 3B). In the upper part of the Raggyorcaka Formation, with the ultimate diminishment and demise of the limestone interbeds, the strata are dominated by several layers of coals with abundant plant fossils (Fig. 3C). The Permian-Triassic boundary is tentatively considered here to be correlate to the formation boundary between the Raggyorcaka Formation and the overlying Kanglu Formation based on lithofacies and biofacies data (Fig. 3D). As has been proposed by Zhang et al. (2019), the eustatic variation of the Raggyorcaka Formation is similar to that in the Qamdo region more than 1000 km in the east. More study is required to study their paleogeographic relationships.

Third locality: Rongma Town, Nyima County

This region is very close to the Longmu Co-Shuanghu suture zone. There are many ophiolites and blueschists preserved in this region. The Permian strata are widely distributed, which were

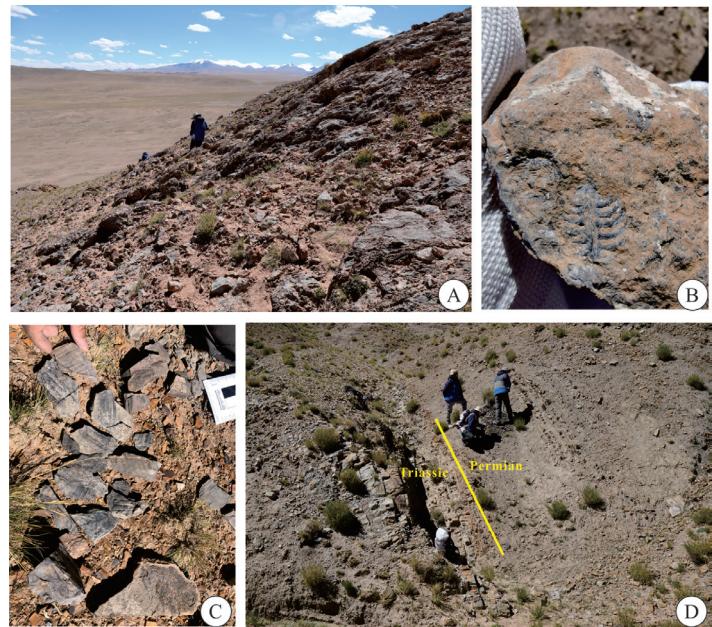


Fig. 3. Permian and PTB strata and biotas in the Raggyorcaka area. A. the limestone of the Xueyuanhe Formation; B. *Leptodus* (brachiopod) in the Raggyorcaka Formation; C. plant fossils in the upper part of the Raggyorcaka Formation; D. probable Permian-Triassic boundary in the Raggyorcaka area

assigned to the Cameng and Zhanjin formations (Institute of Geological Survey of Jilin University, 2005). Due to the strong tectonic deformation in the convergence zone, fossils are not reported in both formations previously. Thus, we didn't check them during the fieldwork.

During the fieldwork, we investigated outcrops in a deep valley to the south of Jiaomuri Hill. The outcrops there are represented by an accretionary complex with different tectonic units (Fig. 4). These units include well-bedded reddish limestone (Fig. 4A), thin-bedded siltstones with sandstone olistostromes (Fig. 4B), well-bedded grey limestones (Fig. 4C) and thin-bedded cherts (Fig. 4D). The ages of these units are not known. However, it is clear that they are accretionary complex related to the subduction of the Paleotethys Ocean beneath the North Qiangtang Block, judging from their field occurrences.

Fourth locality: Wenbu Town, Nyima County

This area is located at Wenbu Town, south of Nyima County. Tectonically, it belongs to the Lhasa Block. The Permian strata in this region consist of the Yunzhub, Largar, Angjie and Xiala formations, in ascending order. We measured two sections. The first one preserves a perfect transition from glaciomarine deposits to marine carbonates (Fig. 5A). The lowermost part of the section is characterized the Largar Formation, which is composed of thick-bedded sandstones, and massive siltstones with common dropstones (Fig. 5B). The dropstones are dominated by quartzite and granites, indicating an exotic glacial origin. The Angjie Formation conformably overlies the Largar Formation. Interestingly, many brachiopod shells were found in the base of the Angjie Formation (Fig. 5C). They occurred directly above or within the conglomerate, suggesting sea-level rise during the



Fig. 4. Permian strata in the Rongma area.

A. accretionary complex in the Longmu Co-Shuanghu suture zone; B. thin-bedded siltstones with sandstone olistostromes; C. Permian thin- to middle-bedded limestone beds; D. cherts beds at a steep angle

initial deglaciation. In the upper part of the Angie Formation, grey thin-bedded siltstones dominated. In the top of the section, the reddish limestone of the Xiala Formation conformably overlies the Angie Formation.

The middle part of the Xiala Formation outcrops in the west of the famous Tangra Yumco Salt Lake, where the sequence is dominated by carbonates with chert nodules (Fig. 5D). Diverse fossils, such as colonial corals, brachiopods and fusulines were collected in the section. Both the coral and fusuline indicate a Guadalupian age for the limestone.

In conclusion, the Permian strata in the Wenbu area represent a transition from glaciomarine deposits (cold climate) to marine carbonate deposits (warm climate). This transition is similar to that in other regions in the Lhasa Block such as in the Xainza, Tsochen and Lhunzhub areas. It suggests that the Lhasa Block was very stable during the Permian.

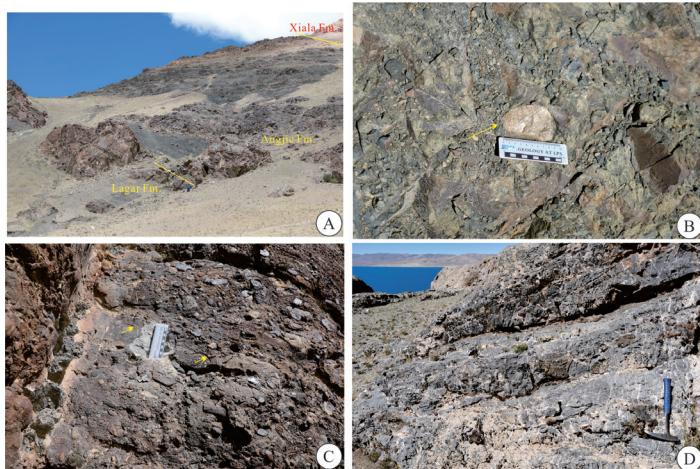


Fig. 5. Permian strata from the Wenbu area, Lhasa Block.

A. Permian section in the north of the Wenbu village; B. dropstones in the Largar Formation; C. brachiopods from the lower part of the Angie Formation; D. Middle Permian limestone beds of the Xiala Formation.

In total, we investigated more than twenty sections in different blocks in the Qinghai-Tibet Plateau. The Permian sequences and faunas in these blocks are quite different, which is of great significance in the reconstruction of the paleogeography.

Acknowledgement

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Comment to Chen et al., 2020: Abrupt warming in the latest Permian detected using high-resolution in situ oxygen isotopes of conodont apatite from Abadeh, central Iran. Importance of correct stratigraphic correlation, reporting of existing data and their scientific interpretation

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This comment was intended to be published in Palaeo3, where the paper we are discussing has been released. However, its editor decided not to consider our contribution without giving any reason. We regard the Abadeh section as one of the most important PTB sections in the world, evidenced by numerous investigations carried out there, therefore an exact and unequivocal high-resolution stratigraphy must be ensured, which we hope to support by this contribution.

We have enjoyed reading the outcome of Chen et al. with its impressive sea surface water temperature curve across the PTB in Iran. However, we are very surprised and concerned about the biostratigraphy applied to the Abadeh section for this so important and sensitive time interval by disregarding major published work. Based on intense research, there is a broad agreement on the position of the PTB interval at Abadeh when following the results of three independent research groups: the first investigation by the Iranian-Japanese-Research Group (IJRG: Taraz et al., 1981) showed the PTB (FO of *Hindeodus parvus*) at the top of the boundary clay, ca. 30 cm above the top of the *Paratirolites* Limestone at the base of the microbialite interval (Fig. 1). This position was subsequently confirmed by Gallet et al. (2000), Horacek et al. (2007) and Richoz et al. (2010) (the latter two part of the same research group), and adopted by Kershaw et al. (2012), Shen et al. (2013), Liu et al. (2013) and Dudas et al. (2017) (all henceforth called GROUP 1, Fig. 1). However, one research group (here called GROUP 2) including Korte et al. (2004, 2010) and Kozur (2004, 2005, 2007) drew the PTB distinctly (ca. 1.4 metres) above the top of the *Paratirolites* Limestone, thereby moving the boundary above their microbialite interval. Shen and Mei (2010) adopted this position, though, as Ghaderi et al. (2014) pointed out, without any own observations or data from this interval. Thereby they artificially extended the range of the Late Permian and pre-extinction conodont *C. hauschkei* across their non-investigated interval until their first data point significantly above the PTB sensu GROUP 1. This completely confuses the PTB interval in Abadeh, because, between the *Clarkina* (*C.*) *hauschkei* and *Hindeodus* (*H.*) *parvus* zones, now there is either no conodont zone [Shen and Mei (2010), adopted by Liu et al. (2013)], or one [*C. meishanensis* – *H. praeparvus* zone (z.) in Korte et al. (2004) and Richoz et al. (2010)] or two conodont zones. [*C. meishanensis* – *H. preparvus* and *Merillina* (*M.*) *ultima* – *Stepanovites?* (S.?) *mostleri* z. (Kozur, 2005, 2007; Korte, 2010)]. The base of the latter zone approximates to the FO of *H. parvus* in Taraz et al. (1981), Gallet et al. (2000), Horacek et al. (2007) and Richoz et al. (2010) (GROUP 1). Chen et al. adopted the low-resolution stratigraphy of Shen and Mei (2010) and thus the higher stratigraphic base of the Triassic of GROUP 2 for reasons we can only speculate (see below).

The PTB-interval represents a period of profound and quick environmental changes, for which a detailed chronology with exact and correct assignment of the boundary is indispensable. Therefore, the decision by Chen et al. to apply a low-resolution and incorrect stratigraphy, is very problematic, resulting in confusion and incorrect conclusions. Specifically we criticize the

following points:

Problems with biochronology and lithostratigraphy

Firstly, by following Mei and Shen (2010), the authors ignore the existence of one [*C. meishanensis*-*H. praeparvus*, Korte et al.(2004), Richoz et al.(2010)], or two latest Permian conodont zones [*C. meishanensis*-*H. praeparvus* and *M. ultima*-*S.?* *mostleri*: Kozur (2005, 2007)] above the *C. hauschkei* zone. Instead, they enlarge this rather short-lived conodont zone, which in the Abadeh section is strongly reduced (just up to 14 cm in the uppermost pre-extinction *Paratirolites* beds) – see Korte et al. (2004), Kozur (2005, 2007) – to an interval of ca. 140 cm across the entire boundary interval.

Secondly, their placement of the PTB in Abadeh is done in a way that seems to us unsound and non-scientific. In Abadeh, GROUP 1 has identified the first occurrence of *Hindeodus parvus* at ca. 30 cm above the top of the *Paratirolites* beds and GROUP 2 at ca. 1 metre higher. The conodonts are well described and displayed in Kozur (2004) and Richoz et al. (2010, pl. 2), with respect to GROUP 2 and GROUP 1. Chen et al. do neither evaluate these documentations nor the ambiguity between the two groups, and do not draw the logic conclusion that GROUP 1, representing three teams, must have correctly identified the boundary, which GROUP 2 (representing one team) has missed. Also, they did not document their own conodont material, which might have added further valuable detailed information. Instead, they claim not having had sufficient material to determine the *Hindeodus* lineage and thus the boundary in the section. This is rather curious, as they obviously had collected enough material to perform the oxygen isotope analysis – assumingly they analysed all material before a proper conodont determination. Inacceptable, however, is Chen's et al. justification of their PTB definition by wrongly quoting Kershaw et al. (2012), that “the biostratigraphic boundary is most likely close to the top of the microbialite bed”. Kershaw et al. (2012), showed in their fig. 9C the PTB in Abadeh at ca. 30 cm above the top of the *Paratirolites* limestone, thus following GROUP 1. Nonetheless, Chen et al. locate the PTB in Abadeh close to the top of the microbialites by adopting the boundary position of GROUP 2 as the correct one.

Thirdly, if Chen et al. (2020) would do follow the claim of Kershaw et al. (2012), they would need to draw the boundary even further up, to 190 cm above the *Paratirolites* beds, as Baud and Richoz (2007, fig. 3a), Richoz et al. (2010, fig. 5), and Kershaw et al. (2012, fig. 9C) show the top of the microbialites at this level.

Fourthly, Chen et al. (2020) failed to show both published PTB levels that have been identified in the section in their figures (nor do they mention them in the captions), but exclusively note the *H. parvus* datum of GROUP 2, persuading a non-in-depth reader that this is the undisputed PTB at Abadeh section. As this is not the case, Chen et al. produce confusion and uncertainty in the stratigraphy of the Abadeh section instead of aiming for clarification and solution of this question.

Consequences

The criticized points in the Chen et al. paper lead to significant errors and problems:

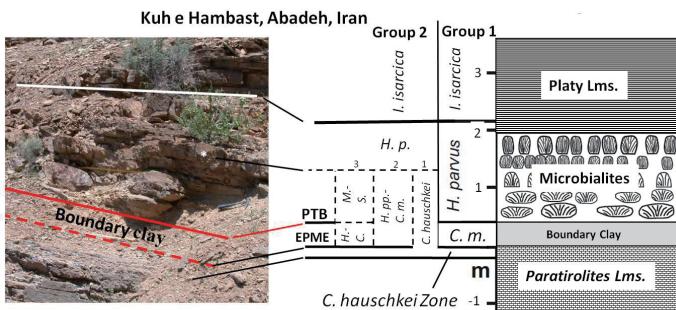


Fig. 1. PTB at Abadeh showing the biostratigraphy of the different research groups and publications. BS: boundary shale, Lms.: Limestone, C.: *Clarkina*, C.m.: *Clarkina meishanensis*, H. p.: *Hindeodus parvus*, H. pp.: *Hindeodus praeparvus*, H.-C.: *Hindeodus praeparvus-Clarkina meishanensis*, I.: *Isarcicella*, M.-S.: *Merillina ultima* – *Stepanovites? Mostleri*. EPME: End Permian Mass Extinction, PTB: Permian-Triassic Boundary. 1: Shen and Mei, 2010; Chen et al., 2020. 2: Korte et al., 2004. 3: Kozur 2005, 2007; Korte et al., 2010. White star in photo: PTB according to GROUP 2. Length of hammer in photo is 35 cm.

Problem 1: By enlarging the *C. hauschkei* zone beyond the entire boundary interval and thus significantly beyond the end-Permian mass extinction event (EPME) – and the quick and strong increase in seawater temperature following the EPME , Chen et al. suggest that *C. hauschkei* might have thrived in the P-T post-extinction hot-water environment of Abadeh. However, this has not been documented in any equatorial Tethyan section so far and appears rather unlikely, as *Clarkina* is a LPL cool-water genus (e.g. Kozur 2007) and usually a decline (or total disappearance) is reported after the EPME (Richoz et al., 2010); this is also evidenced by its absence above the EPME in Chen's et al. dataset.

Problem 2: If the PTB-definition of GROUP 1 (PTB at ca. 30cm above top of the *Paratirolites* limestone) is used, the isotopic results of Chen et al. indicate that the warming trend of the ocean water continues into the basal Lower Triassic at Abadeh. We hypothesize that one reason for their opposing "... conservative option..." in placing the PTB higher up might have been the urge to find an agreement with the recently published seawater-temperature curve of Joachimski et al. (2019). There the increase in seawater-temperature is also restricted to the Late Permian [Interestingly the PTB position in Joachimski et al. (2019) is disputed, too and will be discussed elsewhere]

Conclusions

Theoretically, the placement of the PTB in Abadeh should be straight forward, as three independent working groups [Taraz et al. (1981), Gallet et al. (2000), Horacek et al. (2007), Richoz et al. (2010)] identically determined the boundary and just one research group published diverging results [Korte et al. (2004, 2010), and all further publications by Kozur are based on the same material]. The study by Chen et al. would have been an excellent opportunity to solve and refine the question concerning the exact position of the PTB in Abadeh as a useful by-product of their main aim. Sadly, the authors have failed in this point and

have instead added confusion concerning the PTB position in Abadeh and the range of *C. hauschkei*. Following our correction, the data of Chen et al. of a temperature change from the EPME into the earliest Triassic do agree with those from Meishan, China (Chen et al., 2016; Wang et al., 2020).

Acknowledgments

This is a contribution to IGCP-projects 630 and 710.

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SUBMISSION GUIDELINES FOR ISSUE 71

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The deadline for submission to Issue 71 is July, 31th, 2021

Age (Ma)	Series/stage	Magnetic polarity units	Conodonts		Fusulines	Radiolarians
250	Triassic	Lopingian	I2 I1	<i>Isarcicella isarcica</i> <i>Hindeodus parvus</i>		
252			LP3	<i>Clarkina changxingensis</i> <i>Clarkina subcarinata</i> <i>Clarkina wangii</i>	<i>Palaeofusulina sinensis</i>	Unzoned <i>Albaillella yaoi</i> <i>Neocalbaillella optima</i> <i>Albaillella triangulata</i> <i>Neoalbaillella ornithoformis</i>
254			LP2n	<i>L10</i> <i>L9</i> <i>L8</i>	<i>Palaeofusulina minima</i>	
256			LP1	<i>L7</i> <i>Clarkina orientalis</i>	<i>Gallowayinella meitiensis</i>	<i>Albaillella excelsa</i>
258			LP1.1r	<i>L6</i> <i>Clarkina transcaucasica</i>		<i>Albaillella levis</i>
260			LP0r	<i>L5</i> <i>Clarkina guangyuanensis</i>		<i>Albaillella cavitata</i>
262				<i>L4</i> <i>Clarkina levenii</i>		
264				<i>L3</i> <i>Clarkina asymmetrica</i>		
266				<i>L2</i> <i>Clarkina postbitteri postbitteri</i>		
268				<i>L1</i> <i>Clarkina postbitteri hongshuiensis</i>		
270	Capitanian	Lengwan		<i>G7</i> <i>Jinogondolella granti</i>	<i>Lantschichites minima</i>	<i>Follicucullus charveti</i>
272				<i>G6</i> <i>Jinogondolella xuanhanensis</i>	<i>Metadolliolina multivoluta</i>	<i>Follicucullus scholasticus</i>
274				<i>G5</i> <i>Jinogondolella prexuanhanensis</i>		
276				<i>G4</i> <i>Jinogondolella altudaensis</i> - <i>Jinogondolella shannoni</i>		
278				<i>G3</i> <i>Jinogondolella postserrata</i>	<i>Yabeina gubleri</i>	
280					<i>Afghanella schencki</i> /	<i>Follicucullus porrectus</i>
282					<i>Neoschwagerina margaritae</i>	<i>Follicucullus monacanthus</i>
284						
286						
288						
290	Wordian	Kuhfengian			<i>Pseudoalbaillella globosa</i>	
292						
294						
296						
298						
300	Carboniferous					

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