# A PROPOSAL FOR NEW CHRONOSTRATIGRAPHIC STAGE SUBDIVISIONS OF THE UPPER TRIASSIC SERIES

**Mark W. Hounslow[1,2] & Spencer. G. Lucas[3]**

[1] Lancaster Environment Centre, Lancaster University, Lancaster, UK. LA1 4YW; mark.w.hounslow@gmail.com
[2]Earth, Ocean and Ecological Sciences, University of Liverpool, Jane Herdman Building, Liverpool, UK. L69 3GP.
[3] New Mexico Museum of Natural History and Science,1801 Mountain Road N. W., Albuquerque, New Mexico 87104-1375 USA

**Abstract -** Chronostratigraphic stages that have a short duration are desirable because they identify brief units that can be used to make more detailed and precise age assignments and correlations. Finer-scale substage and zonal subdivisions naturally remain for correlation, but these are outside the formal decision processes of the STS. The longest Phanerozoic stage is the Norian (approximately 18 Myr duration), which is both mismatched in terms of duration with other Phanerozoic stages, and the Lower and Middle Triassic Series, which together are shorter than the Norian Stage. If the Norian was formally divided it would also enhance our understanding of this interval as well as improve chronostratigraphic resolution. We propose the Norian should be raised in rank, and its substages used as new stages. However, such a modification would also require a re-evaluation of the hierarchical position of the Carnian and Rhaetian stages of the Upper Triassic. Given that the Carnian (approximately 10 Myr duration) is one of the longer stages in the Mesozoic it would also benefit with a raised ranking and subdivision to maintain its historical hierarchy with the Norian. We examine three alternative scenarios that raise the rank of the Carnian and Norian (and the Rhaetian Stage) in the chronostratigraphic hierarchy to either series or subseries rank. The existing Upper Triassic substages are also proposed to be raised in rank to stages, allowing formal definition by GSSP boundary stratotypes. The positive and negative issues with any changes in stage and substage hierarchy are examined.

## INTRODUCTION

The chronostratigraphic scale is a nested hierarchy of intervals that has been worked on for more than 200 years. For the Triassic, that hierarchy currently consists of three series and seven stages of formal usage, and 15 substages of less formal usage (Fig. 1). In a chronostratigraphic scale, temporally shorter chronostratigraphic units are desirable because they identify shorter intervals of time that can be used to make more detailed and precise age assignments and correlations. It thus could be said that long chronostratigraphic units are the enemies of precise correlation. An important aspect of improving chronostratigraphic scales should be division into smaller chronostratigraphic units. The Upper Triassic, which includes the longest stage of the Phanerozoic (i.e. the Norian) as well as one of the longer stages (i.e. Carnian), is apt for more refined chronostratigraphic subdivision formally by the STS (Lucas, 2013). Naturally, finer-scale biostratigraphic (also chemostratigraphic, magnetostratigraphic, cyclostratigraphic, etc.) zonal divisions of the stages remain as a means of fine-scale correlation, but formal chronostratigraphic units as defined by the ICS, its subcommissions and the GSSP concepts, are at the level of stages, and not at a lower level in the chronostratigraphic hierarchy (Harper et al. 2022).

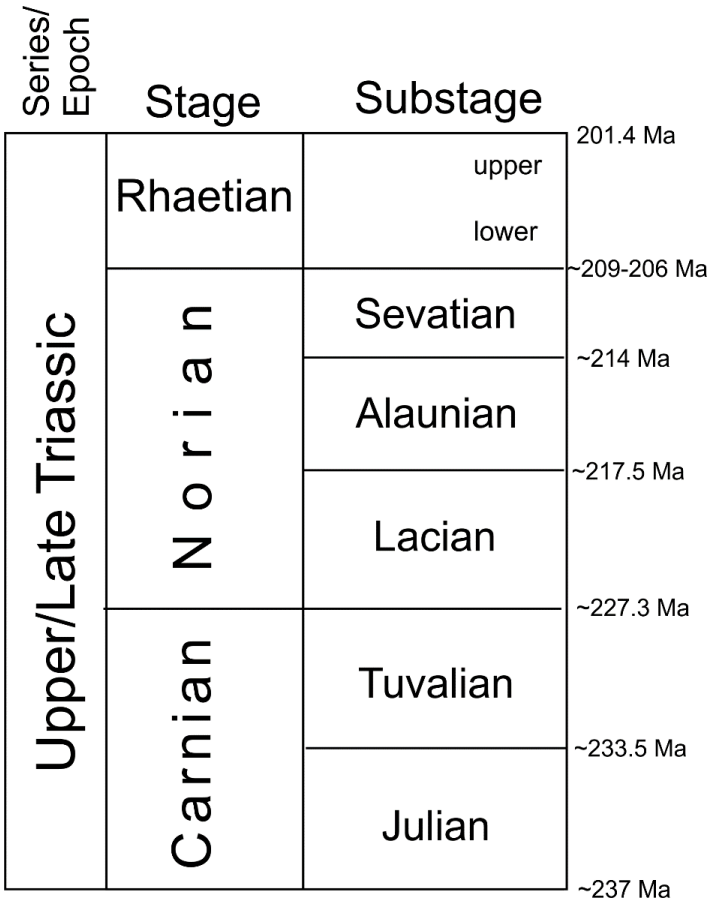


**Fig. 1. Existing divisions of the Upper Triassic as decided by the STS in 1992. The substages were not part of that decision process but have now been widely adopted by workers on the Triassic. Informal divisions of the Rhaetian have also been widely used during the last two decades. The age range for the base of the Rhaetian represents the range of the two proposed alternatives for that boundary. Numerical ages of the boundaries from Ogg et al. (2020), but note that these ages are not accepted by all workers.**

Here, we propose such a refinement of the Upper Triassic chronostratigraphic scale by elevating its substages to stage status and its current stages to higher units in the chronostratigraphic hierarchy. This will produce a better Upper Triassic chronostratigraphic scale, simply because these new units will facilitate more precise age determinations and correlations. This proposal does not impact any finer-scale zonal divisions below the level of stages, which do not fall within the remit of the STS. This proposal is also timely, since whilst the Norian and Rhaetian currently have no formally ratified global stratotype section and point (GSSP), they are both closer to that formal decision. This proposal is focussed on the Upper Triassic, and we do not here consider issues with the Lower and Middle Triassic.

## WHY DO WE NEED TO SUBDIVIDE THE NORIAN?

The Norian is a long stage (longest in the Phanerozoic), and some three times the average stage duration in the Permian- Cretaceous interval (Fig. 3). Using the Geological Timescale 2020 (GTS2020) estimates (Gradstein et al., 2020), the average duration of stages in the Cretaceous, Jurassic and Permian is 6.4, 5.8 and 5.2 Myrs, respectively. This extraordinarily long duration of the Norian Stage was not known for sure when the Upper Triassic was divided into stages by the STS in 1992, but it has become much clearer in the last two decades (Fig. 2).

The duration of the Norian Stage is much more like an epoch than a stage. Using GTS2020, the Norian is longer than 66% of Phanerozoic epochs, which have a median duration of 14.9 Myr.

The Norian Stage is also longer than the Lower and Middle Triassic combined (at 14.9 Myr), which is a clear imbalance in the geochronostratigraphic divisions of the Triassic (Kozur & Bachmann, 2005). This imbalance with the Norian was not clearly known when the STS decision on the stage divisions of the Triassic was made, although the long duration of the Late Triassic was well known prior to 1992 (Fig. 2). Others have expressed similar views to formally subdivide the Norian (Korte et al., 2003; Lucas, 2013; Karádi et al., 2021).

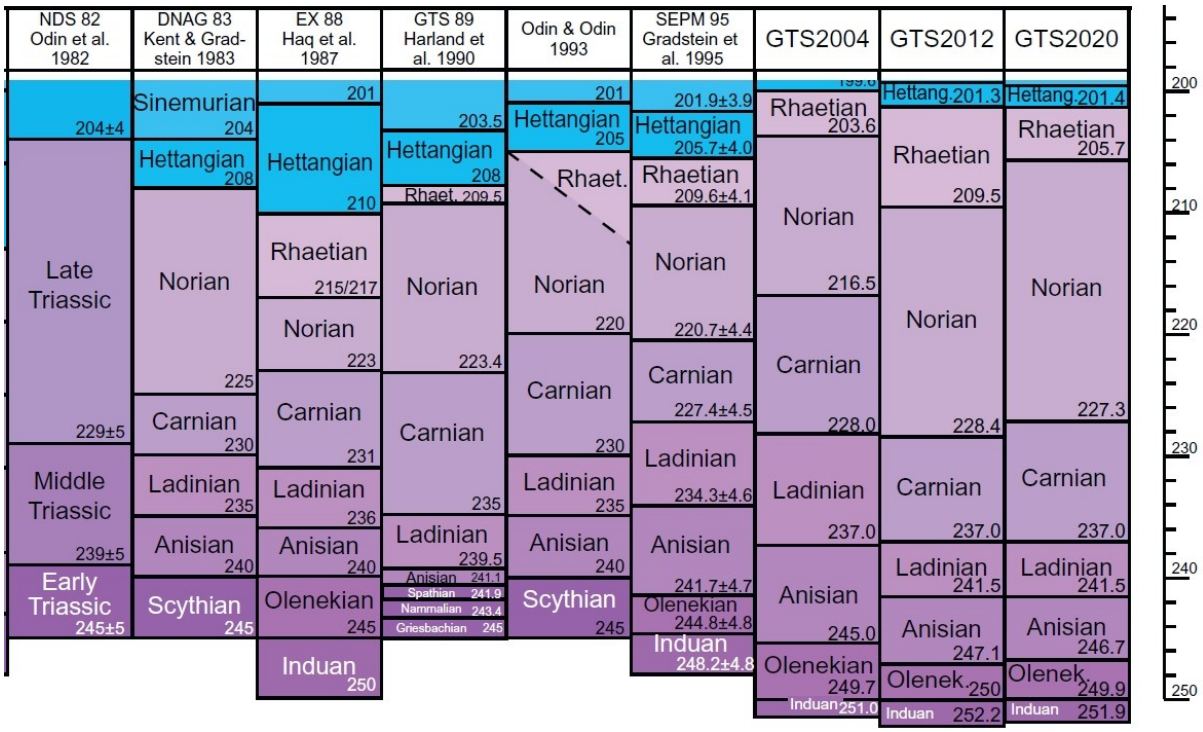


**Fig. 2. The changing durations and ages of the Triassic stages based on important milestones in timescale construction (modified from figure 1.5 of Gradstein et al., 2020).**

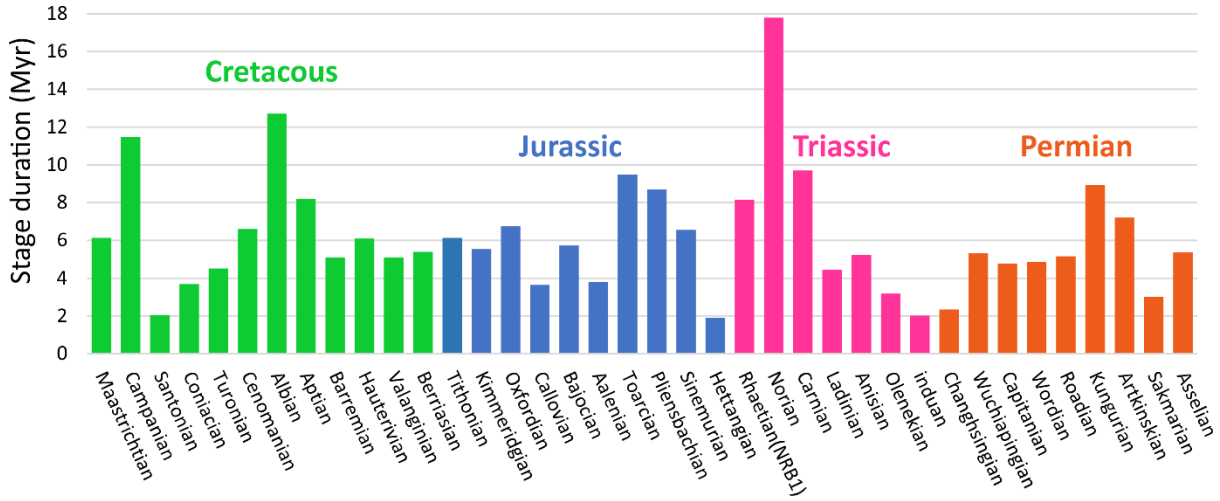


**Fig. 3. Duration of Mesozoic and Permian stages (from Gradstein et al. 2020). NRB1= the older proposed definition for the base of the Rhaetian (using FAD of *Misikella posthernsteini*; Krystyn et al., 2007; Galbrun et al., 2020). Choosing the younger proposed definition for the Rhaetian (NRB2; FAD of *Misikella posthernsteini* s.s.; Bertinelli et al., 2016) gives Rhaetian and Norian estimated durations of 4.4 Myr and 21.6 Myr, respectively, exacerbating the problem of a long Norian, if this option were chosen as the GSSP for the**

**base of the Rhaetian. We have chosen to focus on Mesozoic stages for this, but include the Permian, since the Triassic and Permian often have much commonality in many regions.**

## Consequences of a long Norian

A long Norian has consequences for chronostratigraphic division, which if left unchanged will diminish the precision with which the timing of climatic and biotic events during the Norian can be understood and correlated. A sub-division of the Norian does not change the finer-scale zonal subdivisions of the Norian, although it would likely promote more work on them. This is all the more significant in that major biotic and environmental changes occur within this interval (Irmis et al., 2010).

The increasing use of the existing Norian substages (Fig. 4) indicates a demand that studies in geological science use a more refined Upper Triassic chronostratigraphic scale beyond the existing stage usage. However, without definition and revision of the substages and bringing them into the GSSP boundary stratotype concept, the substages of the Norian will remain imprecise and open to the vagaries of authors interpretation of the guide fossil chosen. A similar view was also expressed by Karádi et al. (2021) and Haas & Budai (1999). Naturally, not all have used the Norian substage names as in Fig. 1; lower, middle, and upper divisions of the Norian have also been used reflecting regional differences in ammonoid zonations (Orchard & Tozer, 1997; Konstantinov & Klets, 2009).

Because the GSSP definition project of the International Commission of Stratigraphy (ICS) is only based around defining stage bases (not substages or zones), formal chronostratigraphic definitions of substages (using GSSP concepts) are unlikely to come about soon. It this therefore important for the STS to address an internationally agreed, formal, finer-scale subdivision of the Norian.

Workers in some geological periods, which have well-developed regional substages (e.g., the Carboniferous) have evolved workarounds to handle the imprecision of too-long stages by proposing formal regional substages as international divisions of those stages (Poty et al., 2014; Cózar et al. 2023). This is not a viable option for the Norian (or Upper Triassic), since there is no long history of common regional substage name usage. Regional differences (e.g., New Zealand Triassic stages) are seen to be of similar rank to current Triassic international stages with those in China also the case (Tong et al., 2019).

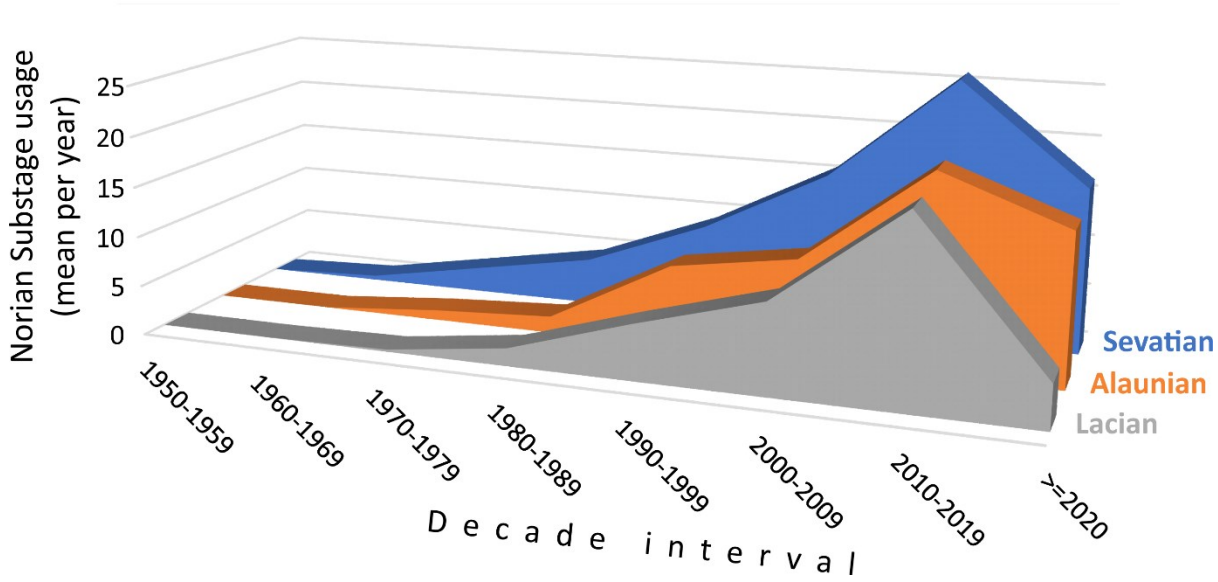


**Fig. 4. Norian substage usage in decade intervals since 1950 (x-axis). Mean usage per year shown on the y-axis. Data derived from Google Scholar in late 2022. Blue=Sevatian, orange=Alaunian, grey=Lacian. Clearly these changes are also in part related to the expansion of published papers on-line about the Upper Triassic (grey curve in Fig. 5).**

## CONSEQUENCES OF SUBDIVIDING THE NORIAN INTO NEW STAGES

Any revision of the Norian needs some modification of the adjacent epoch/series (or subseries) divisions to maintain a consistent hierarchy. Keeping the Norian as a chronostratigraphic unit would promote stability in stratigraphic terminology for the geological community, connecting past and future usage. Discarding it would likely be deeply unpopular because of its long historical precedence back to the Triassic timescale of Mojsisovics et al. (1895). We therefore propose to upgrade the Norian to a higher chronostratigraphic rank (i.e., a series or subseries; Harper et al. 2022; see also stratigraphy.org/guide/pref).

The Carnian is also one of the longer stages in the Permian to Cretaceous interval (Fig. 2), and for this feature and the above rank change to the Norian, we propose that the Carnian also be raised in rank and sub-divided into new stages using its widely used substages (Figs. 1, 5). This maintains the historical equivalence of the Carnian and Norian in the chronostratigraphic hierarchy. Carnian regional substage usage has been like that of the Norian, with lower and upper Carnian divisions based on differences in regional ammonoid zonations (Orchard & Tozer, 1997; Konstantinov & Klets, 2009).

Hence, we suggest both the Carnian and Norian be upgraded to either epoch/series status or subepoch/subseries status, as shown in Figure 6. The consistency of this upgrading for both can readily be seen to be rooted in the current Triassic timescale, which is essentially based around that of Mojsisovics et al. (1895) in which Carnian and Norian are of equivalent rank in the hierarchy (Lucas, 2010).

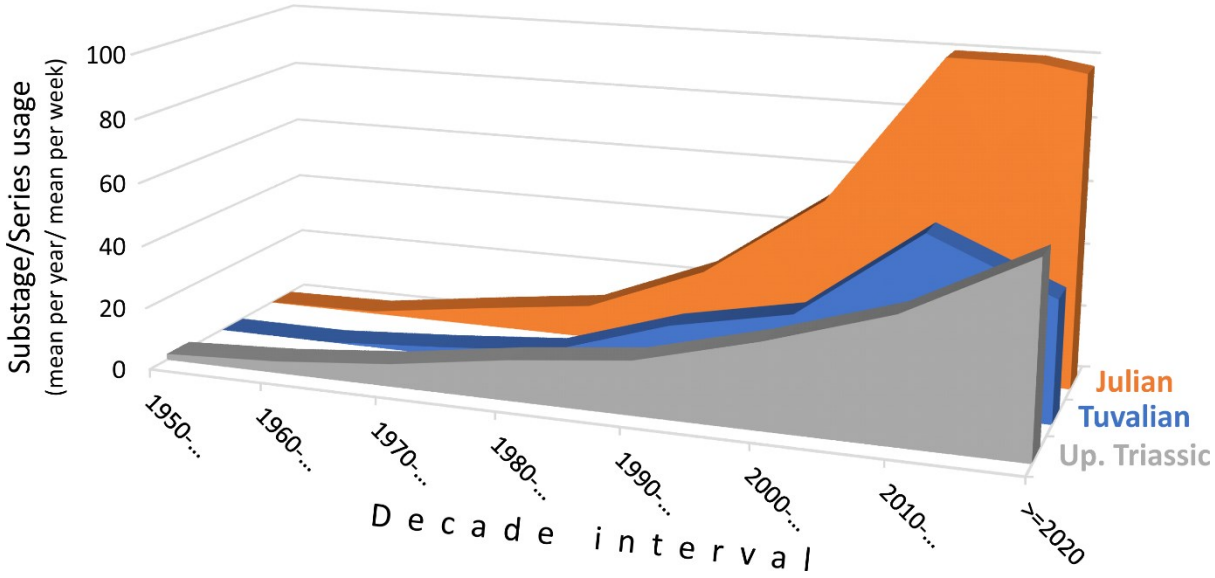


**Fig. 5. Carnian substage usage in papers in decade intervals since 1950 (x-axis). The mean number of usages per year is shown on the y-axis. The data for usage of 'Upper Triassic' (grey block) is also shown as an average of the numbers of papers per week for comparison, also reflecting an expansion in on-line work. Data derived from Google Scholar in late 2022.**

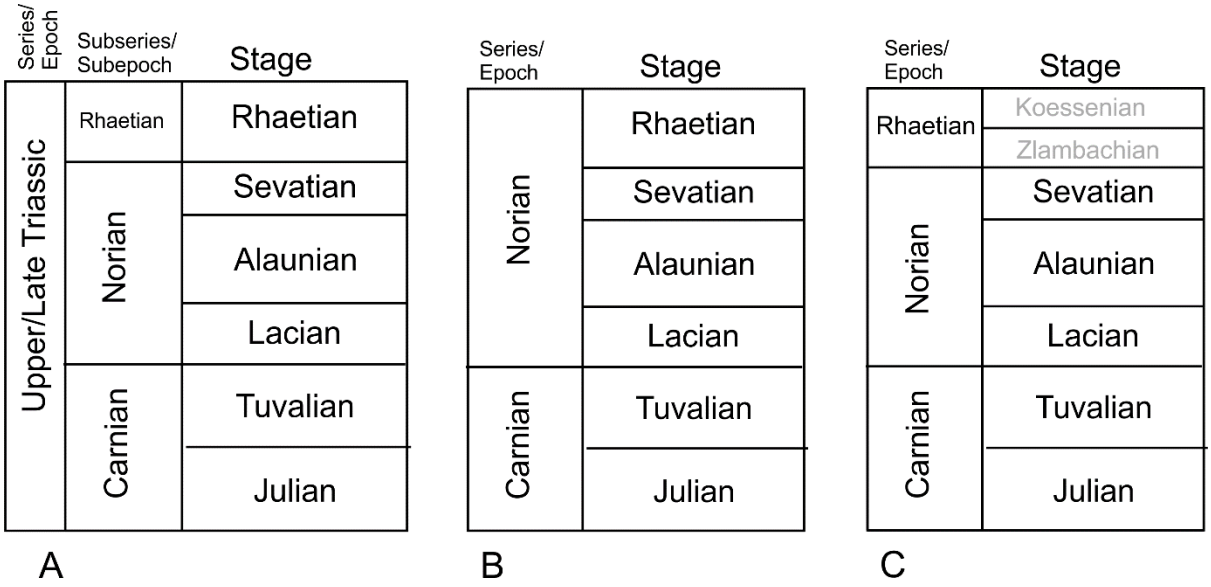


**Fig. 6. Alternative choices of how to sub-divide the Upper Triassic. A and C are new proposals, and B is that suggested by Lucas (2013). See text for discussion of these.**

The substage divisions of the Carnian-Norian (Fig. 1) also have a strong historical precedence in the Triassic timescale proposed by Mojsisovics et al. (1895), which likewise forms the basis for the current substage divisions of the Upper Triassic (Lucas, 2010). This historical hierarchical connection therefore strengthens the usage proposed here of upgrading the existing substages to new Triassic stages (i.e. as the Julian, Tuvalian, Lacian, Alaunian and Sevatian stages).

Perhaps some might consider these substage names as distinctly provincial, being based around usage in Tethyan sections, and that lower, middle and upper Norian are more widely used

divisions of the Norian. According to stratigraphic usage a regional-based or location-based name needs to be used for stages (Murphy & Salvador 1999), so up-ranking the Norian would invalidate lower, middle and upper as acceptable subdivisions.

## ADVANTAGES OF ALSO UP-RANKING THE CARNIAN STAGE

Significantly for the Carnian, there has been an expansion of research works on the Carnian pluvial episode (CPE) focused on the late Julian (seen by wider usage of 'Julian'; Fig. 5). A new stage boundary placed at the base of a new Tuvalian Stage would greatly assist more precise chronostratigraphic correlation connected with events associated with the CPE, events which are known to cross the Julian-Tuvalian boundary (e. g., Dal Corso et al., 2015).

The CPE is also perhaps the most significant environmental event in the Upper Triassic, so additional chronostratigraphic precision near the base of the Tuvalian would assist longer-term with global correlation and understanding the synchroneity of these events.

Elevating the Julian and Tuvalian to stages would bring the approximate duration of stages in the Carnian to the same as that seen in many others stages in the Mesozoic-Permian, i.e., closer to ca. 4-5 Myr in duration (Fig. 1).

## POSSIBILITIES FOR HIERARCHICAL UP-RANKING OF EXISTING STAGE NAMES

Upgrading the hierarchy level of Carnian-Norian-Rhaetian will require that these either become series/epoch intervals (B, C in Fig. 6) or subseries (A in Fig. 6). Another option allowed in stratigraphic usage is superstages (Murphy & Salvador 1999), but this has rarely been favoured, and is not advocated here.

A first option is to upgrade Carnian and Norian to subseries/subepochs (option A in Fig. 6). Formal acceptance of subseries in the current ICS chart has been deemed acceptable for the Carboniferous and Cenozoic (Heckel & Clayton, 2006; Head & Gibbard, 2015) and more widely in chronostratigraphic usage (Harper et al. 2022; see stratigraphy.org/guide/pref). Currently subseries names are restricted to early/lower, middle, or late/upper, but new formal subseries should be named. The current guidelines suggest "A new subseries name should be derived from a geographic feature in the vicinity of its stratotype or type area" (from stratigraphy.org/guide/chron). Option A would also keep Upper/Late Triassic as a Series/Epoch, at the same rank as the Lower Triassic and Middle Triassic, preserving the 3-fold subdivision of the Triassic, which was started with the scale of Friedrich von Alberti.

A second option is to upgrade Carnian-Norian-Rhaetian to epoch/series status (options B and C in Fig. 6), like that used in the Cenozoic, Cambrian, Permian and Carboniferous divisions. This option would dispense with the formal usage of 'Upper Triassic', or 'Late Triassic,' which would then still be used as informal terms referring to the Carnian-Norian-Rhaetian interval (i.e. informal upper and late Triassic, but formal Lower/Early and Middle Triassic). A similar decision was made in the Permian chronostratigraphic scale, in which the three Permian series now have formal names (Cisuralian, Guadalupian and Lopingian), and the terms lower, middle, and upper Permian are an informal usage (Lucas & Shen, 2018). Similar decisions have been made for series/epochs in the Cambrian, Silurian, Carboniferous, Paleogene and Neogene. In these periods, written usage has evolved to be more precise in defining chronostratigraphic intervals and positions. For example, in geochronologic terms one could refer to the rather cumbersome 'middle Late Triassic' in existing usage, but in the new usage proposed in option C, this could be middle Alaunian, or Alaunian or middle Norian. Which of these is chosen would depend on desired intent, scope and geochronologic

precision of the relevant dataset. Options B and C therefore allow added flexibility, precision, and conciseness in chronostratigraphic usage.

## HOW TO DEAL WITH THE RHAETIAN IN THIS UP-RANKING?

The option shown as B in Fig. 6, whilst adhering to North American practice prior to 1992 as advocated by Tozer (1994), would not adhere to the spirit of the STS decision in 1992, identifying a separate Rhaetian above the Norian. However, option B would still maintain the Sevatian Stage as being older than the Rhaetian Stage. Option B would also clearly change the chronostratigraphic interval represented by the Norian Series and the current Norian Stage, which could be unpopular.

Any upper boundary of a new Sevatian Stage would depend on the decision of the STS Rhaetian Working Group. If the older option of Krystyn (2010) was chosen it could make the Sevatian a rather brief stage, whereas if the younger option of Rigo et al. (2016) were chosen this would make the Sevatian a longer interval. How long or short the Sevatian would be is clearly dependent on any formal definition of its base. In terms of priority Sevatian is ranked with the Lacian and Alaunian back to the timescale of Mojsisovics et al. (1895), so this seems a natural choice for an upper Norian division.

If the Rhaetian is upgraded to a formal subseries/subepoch, as is suggested for the Carnian and Norian, then the simplest option would be a dual use for Rhaetian, with it also as a stage (option A; Fig. 6). Hence, this option would use both Rhaetian Subseries and Rhaetian Stage. Whilst formally these are two separate chronostratigraphic items of differing rank, they would still represent the same interval in chronostratigraphic terms.

Subdivision of the Rhaetian into lower and upper has been quite widely used. However, this usage has no formal decision on how to divide it into upper and lower Rhaetian (Shevyrev, 2006). There is clearly some need to solidify formal sub-divisions of the Rhaetian. Since 2010, and using Google Scholar, there have been 431 and 297 papers using ‘upper Rhaetian’, and ‘lower Rhaetian’, respectively, and 759 and 475 papers using ‘late Rhaetian’ and ‘early Rhaetian’, respectively. This suggests some stability in chronostratigraphic usage is required in Rhaetian subdivision.

A division into Rhaetian-1, Rhaetian-2 and Rhaetian-3, as suggested by Krystyn (2008), has also been proposed as an informal subdivision, based on the numbering of ammonoid zones from the Tethyan zonation. This usage is like divisions based on the numbering of Tethyan ammonoid zones in the Carnian-Norian substages (Rigo et al., 2018), used by some workers. However, other authors working in other regions have used no informal subdivisions of the Rhaetian Stage (e. g.,, Orchard & Tozer, 1997; Konstantinov & Klets, 2009; Tong et al., 2019)

With a Rhaetian Series as in option C (or option A), it may be formally more acceptable to sub-divide the Rhaetian Series (or subseries) into two formal new stages, corresponding to the upper and lower parts of the Rhaetian Series (speculative greyed names in option C; Fig. 6). There are currently older and younger choices for the Norian-Rhaetian boundary GSSP. If the older option (Krystyn, 2010) is chosen it could make a two-fold division of the Rhaetian Series more viable. If the younger option (Rigo et al., 2016) is chosen it may make the lower division of the Rhaetian Series less viable, and perhaps no division would be acceptable.

The name Rhaetian is rooted in the original usage of Gumbel (1859, 1861) where the ‘Rhätische Gebilde’ referred to what is now the Kössen Formation in Austria (Lucas, 2010). Mojsisovics et al. (1895) also followed this, in that their ‘Rhaetisch’ was equivalent to the ‘Koessener Schichten’. Hence, a rather speculative new name for a division of a new Rhaetian Series could be Koessenian (from town of Kössen). Using this same region in Austria, a possible name for any

alternate division may be Zlambachian (from the Zlambach Graben), because the Zlambach Beds are the alternate part of the reef-basin systems in the Northern Calcareous Alps (Mette et al., 2019).

Other alternatives are, of course, possible, utilising other areas with key Rhaetian successions (e.g. west-central Nevada or western British Columbia). However, we are NOT advocating here any particular choice for sub-dividing a new Rhaetian Series or Subseries. We instead propose the STS Rhaetian-working group could decide on any new division of the new Rhaetian Series/Subseries, pending their decision on the base of the current Rhaetian Stage. A precedent for doing this could be the discussions on the Albian GSSP, where substages were proposed (with suitable guide markers) for dividing the Albian by the Albian working group (Hart et al., 1996). Of course, defining sub-stages is an informal decision, and not part of any STS formal decision process, although some other systems, such as the Carboniferous (Heckel and Clayton, 2006), have more 'formally' recognised regional substages.

## SUMMARY OF THE OPTIONS FOR CHANGING THE UPPER TRIASSIC HIERARCHY

- Option A (Fig. 6) is perhaps the choice with the least disruption to existing chronostratigraphic usage. However, this would deviate from the existing ICS usage of subseries as only lower, middle, upper only. However, such a deviation is allowed in ICS guidelines. This would also maintain the three-fold Series division of the Triassic (with initial capitals) of Lower, Middle and Upper.
- Option C is consistent with series/epoch divisions in other Periods in the ICS chronostratigraphic chart. The change for option C would be that Upper/Late Triassic becomes informal upper/late Triassic, but conversely this allows for rather more precise use of chronostratigraphic terminology.
- Both options A and C requires that the Rhaetian Working Group decide how to deal with any formal or informal subdivisions of the new Rhaetian Series or Subseries.
- Option B is like option C but would see a return to Tozer's concept of the Norian, and therefore abandonment of the STS decisions in 1992. However, this would require no changes to the formal or informal subdivisions of the Rhaetian.
- The existing decision on the base Carnian GSSP would become a decision for the Julian Stage, and the impending decisions for the basal Norian (Hounslow et al., 2021) becomes a decision for the base of the Lacian Stage and Norian Series/Subseries.
- New working groups would need to be established for deciding GSSP's for the Tuvalian, Aluanian and Sevatian Stages. A provisional list of possible candidate sections is in Table 1, just to illustrate that with some years of additional work, 'off the-shelf candidates' are available.

| **Section** | **Known guides** | **Thickness (metres)** | **reference** |
|---|---|---|---|
| **Sections for a Tuvalian Stage GSSP** | | | |
| Pignola-2 | Conodonts, miospores, magstrat | ~40 | Maron et al., 2017 |
| Dibona | Conodonts, magstrat | ~180 | Maron et al., 2017 |
| Portella/Sella Ursic sections | Miospores | ~200 | Roghi, 2004 |
| Ma'antang, Hanzeng | Conodonts, C-isotopes | ~100 | Shi et al. 2019; Jin et al. 2022b |
| **Sections for a Aluanian Stage GSSP** | | | |

| | | | |
|---|---|---|---|
| Kavur Tepe | Conodonts, magstrat | ~40 | Gallet et al., 1993 |
| Pizzo Mondello | Conodonts, magstrat | ~100 | Mazza et al., 2012 |
| Brown Hill, Pardonet Hill west, Childerhose Cove, Carbon Creek east, Pink Mountain | Ammonoids, conodonts, | 50? | Orchard 1991, 2018. |
| **Sections for a Sevatian Stage GSSP** | | | |
| Kavur Tepe | Conodonts, magstrat | ~40 | Gallet et al., 1993 |
| Pizzo Mondello | Conodonts, magstrat, C-isotopes | ~100 | Mazza et al., 2012 |
| Kavaalani | Conodonts, magstrat | ~20 | Gallet et al., 2000 |
| Tahtaiskele | Foraminifera | 508 | Coskun Tunaboylu et al., 2014 |
| Kiso River | Conodonts, radiolarian | 15 | Yamashita et al., 2018 |
| Hongyan-B | Conodonts, C-isotopes | 60 | Jin et al., 2022a |
| Black Bear Ridge, Pardonet Hill west, Brown Hill, Haidi Gwaii | Ammonoids, conodonts, bivalves, | 50+ | Orchard et al., 2001 |

**Table 1. A preliminary list of potential candidate sections for the new stages proposed here. This list is simply illustrative of some known possibilities that with further work may be shown to be viable or otherwise. Note that this list rather underrepresents ammonoids, since there are few specific sections we could find in which published material at these boundaries has also been related to detailed ammonoid studies.**

## NEGATIVES ISSUES WITH OF A REVISION OF THE UPPER TRIASSIC CHRONOSTRATIGRAPHY

Change of chronostratigraphic terms is naturally annoying to geologists because it involves revising and re-learning new names and divisions (Knox et al., 2012). However, the proposals here limit this in a practical sense to only any divisions of the new Rhaetian Series or Subseries. The existing chronostratigraphic names remain, they are simply promoted in hierarchy, without a change of stratigraphic interval (the exception here is option B; Fig. 6).

In Option C the loss of the Upper Triassic as a formal stratigraphic term will be troubling to some, but it will remain as an informal (non-capitalised upper) for use. Workers in other periods have evolved to deal with similar changes in adequate ways (as mentioned above). This change gives greater flexibility and precision in usage of chronostratigraphic terms, presumably one of the reasons workers in other periods abandoned Upper/Late for series/epochs.

The GSSP point (FAD of *Halobia austriaca* at Pizzo Mondello) selected by the Norian working group (Hounslow et al., 2021) as the base of the current Norian Stage would now become a decision for the base of the new Lacian Stage, and the base of the Norian Series/Subseries. Because the formal proposal for this to the STS is in progress, this small change can easily be dealt with.

It is proposed here that the remit of the Norian-Rhaetian boundary working group is expanded to decide on both the base of the new Rhaetian Series, and informally to decide on its possible subdivision (or no subdivision). This seems a natural procedure to deal with any changes in the sub-division of the Rhaetian as a unit, as has been done in a similar manner with other Phanerozoic stages.

Should we wait for formal GSSP definition of all Upper Triassic stages before discussing changing their hierarchy? Probably not, since: 1) this would lengthen the time to eventual

stabilisation of Triassic stages. 2) Delay GSSP definition of any new stages that are deemed appropriate, if the STS where to agree a revision of the Upper Triassic chronostratigraphic hierarchy.

## CONCLUSIONS

Advances in chronostratigraphic resolution and precision can be achieved by eliminating very long chronostratigraphic units (such as the Norian Stage) by subdividing them into shorter units. This does not change the usage of finer-scale substage or zonal subdivisions, which, however, are not part of the formal decision processes of the STS or the ICS. Implementing this change for the excessively long Norian will also correct the imbalance in duration between this and the Lower and Middle Series of the Triassic. This change also impacts the Carnian and Rhaetian, which should be similarly upgraded in chronostratigraphic rank. The Carnian and Norian are already divided into widely recognized and well used substages that can be elevated to the rank of stage to provide a more detailed Upper Triassic chronostratigraphy. Such a chronostratigraphy will improve the precision of Late Triassic age determinations and correlations. Elevating the ranks of Upper Triassic chronostratigraphic units followed by their formal definition is a logical step forward in the development of the Triassic timescale. Any decision on formal subdivisions of the new Rhaetian Series/Subseries should be made by the Rhaetian working group.

## ACKNOWLEDGEMENTS

Comments from the reviewers Mike Orchard and Marco Balini and the editor Chris McRoberts helped revisions focus on more of the key issues.

## REFERENCES

Coskun Tunaboylu, B., Altiner, D., Isintek, I. & Demirci, D., 2014. Foraminiferal biostratigraphy and sequence stratigraphy of peritidal carbonates at the Triassic–Jurassic boundary (Karaburun Peninsula, Western Turkey). Journal of Asian Earth Sciences, 90: 61-76.

Cózar, P; Somerville, I.D., Hounslow, M.W. 2023. A potential global chronostratigraphic boundary for the base of the middle Viséan. Newsletters in Stratigraphy, doi: 10.1127/nos/2023/0746.

Bertinelli, A., Casacci, M., Concheri, G., Gattolin, G., Godfrey, L., Katz, M.E., Maron, M., Mazza, M., Mietto, P., Muttoni, G. & Rigo, M., 2016. The Norian/Rhaetian boundary interval at Pignola-Abriola section (Southern Apennines, Italy) as a GSSP candidate for the Rhaetian Stage: an update. Albertiana, 43: 5-18.

Dal Corso, J., Gianolla, P., Newton, R.J., Franceschi, M., Roghi, G., Caggiati, M., Raucsik, B., Budai, T., Haas, J. & Preto, N., 2015. Carbon isotope records reveal synchronicity between carbon cycle perturbation and the “Carnian Pluvial Event” in the Tethys realm (Late Triassic). Global and Planetary Change, 127: 79-90.

Galbrun, B., Boulila, S., Krystyn, L., Richoz, S., Gardin, S., Bartolini, A. & Maslo, M., 2020. " Short" or" long" Rhaetian? Astronomical calibration of Austrian key sections. Global and Planetary Change, 192: doi.org/10.1016/j.gloplacha.2020.103253.

Gallet, Y., Besse, J., Krystyn, L., Théveniaut, H. & Marcoux, J., 1993. Magnetostratigraphy of the Kavur Tepe section (southwestern Turkey): A magnetic polarity time scale for the Norian. Earth and Planetary Science Letters, 117: 443-456.

Gallet, Y., Besse, J., Krystyn, L., Marcoux, J., Guex, J. and Théveniaut, H., 2000. Magnetostratigraphy of the Kavaalani section (southwestern Turkey): Consequence for the origin of the Antalya

Calcareous Nappes (Turkey) and for the Norian (Late Triassic) magnetic polarity timescale. Geophysical Research Letters, 27: 2033-2036.

Gradstein, F.M., Ogg, J.G., Schmitz, M.D. & Ogg, G.M. eds., 2020. *Geologic time scale 2020*. Elsevier.

Gümbel, C. W. Von. 1859. Über die Gleichstellung der Gesteinmasen in den nord-östlichen Alpen mit ausseralpinen Flötzschichten. Verhandlungen Gesellschaft Deutsches Naturforschung und Ärtzte Karlsruhe, 54: 80–88.

Gümbel, C.W. Von. 1861. Geognostische Beschreibung des bayerischen Alpengebirges. J. Perthes, Gotha.

Haas, J. & Budai, T., 1999. Triassic sequence stratigraphy of the Transdanubian Range (Hungary). Geologica Carpathica, 50: 459-475.

Harper, D.A.T., Bown, P.R. & Coe, A.L. 2022. Chronostratigraphy: understanding rocks and time. In: Coe, A.L. *Deciphering Earth History: the practice of stratigraphy.* Geological Society of London, Geoscience in Practice, 227-243.

Hart, M.B., Amédro, F. & Owen, H.G., 1996, The Albian Stage and Substage boundaries: Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre, 66: (Supplement) 45–56.

Head, M.J. & Gibbard, P.L., 2015. Formal subdivision of the Quaternary System/Period: Past, present, and future. Quaternary International, 383: 4-35.

Heckel, P. H. & Clayton, G. 2006. The Carboniferous System: Use of the new official names for the subsystems, series, and stages. Geologica Acta, 4: 403-407.

Hounslow, M.W, Bachmann, G.H, Balini, M., Benton, M.J., Carter, E.S., Konstantinov, A.G., Golding, M.L., Krystyn, L., Kuerschner, W., Lucas, S.G., McRoberts, C.A., Muttoni, G., Nicora, A., Onoue, T., Orchard, M.J., Ozsvárt, P., Paterson, N.W., Richoz, S., Rigo, M., Sun, Y., Tackett, L.S., Tekin, U.K., Wang, Y., Zhang, Y. & Zonneveld, J.P. 2021. The case for the global stratotype and section and point (GSSP) for the base of the Norian Stage. Albertiana, 46: 25–57.

Irmis, R.B., Martz, J.W., Parker, W.G. & Nesbitt, S.J., 2010. Re-evaluating the correlation between Late Triassic terrestrial vertebrate biostratigraphy and the GSSP-defined marine stages. Albertiana, 38: 40-52.

Jin, X., Du, Y., Bertinelli, A., Shi, Z., Preto, N., Zou, H., Ogg, J.G., Han, L., Wu, Q. and Rigo, M., 2022a. Carbon-isotope excursions in the Norian stage (Upper Triassic) of the Baoshan terrane, western Yunnan, China. Journal of Asian Earth Sciences, 230, doi.org/10.1016/j.jseaes.2022.105215.

Jin, X., Franceschi, M., Martini, R., Shi, Z., Gianolla, P., Rigo, M., Wall, C.J., Schmitz, M.D., Lu, G., Du, Y. & Huang, X., 2022b. Eustatic sea-level fall and global fluctuations in carbonate production during the Carnian Pluvial Episode. Earth and Planetary Science Letters, 594: doi.org/10.1016/j.epsl.2022.117698

Karádi, V., Kolar-Jurkovšek, T., Gale, L. & Jurkovšek, B., 2021. New advances in biostratigraphy of the Lower/Middle Norian transition: Conodonts of the Dovško Section, Slovenia. Journal of Earth Science, 32: 677-699.

Konstantinov, A.G. & Klets, T.V., 2009. Stage boundaries of the Triassic in Northeast Asia. Stratigraphy and Geological Correlation, 17: 173-191.

Korte, C., Kozur, H.W., Bruckschen, P. & Veizer, J., 2003. Strontium isotope evolution of Late Permian and Triassic seawater. Geochimica et Cosmochimica Acta, 67: 47-62.

Kozur, H.W. & Bachmann, G.H., 2005. Correlation of the Germanic Triassic with the international scale. Albertiana, 32: 21-35.

Knox, R.O.B., Pearson, P.N., Barry, T.L., Condon, D.J., Cope, J.C.W., Gale, A.S., Gibbard, P.L., Kerr, A.C., Hounslow, M.W., Powell, J.H. and Rawson, P.F., 2012. Examining the case for the use of the Tertiary as a formal period or informal unit. Proceedings of the Geologists Association, 123: 390-393.

Krystyn, L. 2008. An ammonoid-calibrated tethyan conodont time scale of the late Upper Triassic. Berichte Geol. B.-A., 76: 9-11.

Krystyn, L., 2010. Decision report on the defining event for the base of the Rhaetian stage. Albertiana, 38: 11-12.

Krystyn, L., Richoz, S., Gallet, Y., Bouquerel, H., Kürschner, W.M. & Spötl, C., 2007. Updated bio-and magnetostratigraphy from Steinbergkogel (Austria), candidate GSSP for the base of the Rhaetian stage. Albertiana, 36: 164-173.

Lucas S.G. 2010. The Triassic chronostratigraphic scale: history and status. In: Lucas. S.G. (ed). The *Triassic Timescale.* Geological Society, London, Special Publications 334:17-39

Lucas, S.G., 2013. A new Triassic timescale. In: Tanner, LH, Spielmann, JA, & Lucas, SG, (eds.) *The Triassic System.* New Mexico Museum of Natural History and Science Bulletin, 61: 366-374.

Lucas, S. G. & Shen, S. 2018. The Permian chronostratigraphic scale: History, status and prospectus. In: Lucas, S. G. and Shen, S. Z. (eds.) The Permian Timescale. Geological Society, London, Special Publications, 450: 21-50.

Maron, M., Muttoni, G., Dekkers, M.J., Mazza, M., Roghi, G., Breda, A., Krijgsman, W. & Rigo, M., 2017. Contribution to the magnetostratigraphy of the Carnian: new magneto-biostratigraphic constraints from Pignola-2 and Dibona marine sections, Italy. Newsletters on Stratigraphy, 50: 187-203.

Mazza, M., Rigo, M. & Gullo, M., 2012. Taxonomy and biostratigraphic record of the Upper Triassic conodonts of the Pizzo Mondello section (western Sicily, Italy), GSSP candidate for the base of the Norian. Rivista Italiana di Paleontologia e Stratigrafia, 118: 85-130.

Mette, W., Clemence, M.E., Thibault, N., Korte, C., Konrad, B. & Ullmann, C.V., 2019. Sedimentology, carbon isotope stratigraphy and micropalaeontology of the Rhaetian Zlambach Formation–Implications for the Dachstein carbonate platform development (Northern Calcareous Alps, Austria). Sedimentary Geology, 382: 47-60.

Mojsisovics, E. Von, Waagen, W. H. & Diener, C. 1895. Entwurf einer Gliederung der pelagischen Sediments des Trias-Systems. Akademie Wissenschaft Wien, Mathematische-naturwissenschaftliche Klasse Sitzungsberichte, 104: 1279–1302.

Murphy, M.A. and Salvador, A., 1999. International stratigraphic guide—an abridged version. Episodes, 22: 255-271.

Ogg, J.G., Chen, Z.Q., Orchard, M.J. & Jiang, H.S. 2020. The Triassic Period. In: Gradstein, F.M., Ogg, J.G., Schmitz, M.D. and Ogg, G.M. (eds), Geologic Time Scale 2020, Elsevier, 903-953. DOI: https://doi.org/10.1016/B978-0-12-824360-2.00025-5.

Orchard, M.J., 1991. Upper Triassic conodont biochronology and new index species from the Canadian Cordillera. Geological Survey of Canada Bulletin, 417: 299-335.

Orchard, M.J., 2018. The lower-middle Norian (Upper triassic) boundary: new conodont taxa and a refined biozonation. Bulletins of American Paleontology. 395/396: 165-193.

Orchard, M.J. & Tozer, E.T., 1997. Triassic conodont biochronology, its calibration with the ammonoid standard, and a biostratigraphic summary for the Western Canada Sedimentary Basin. Bulletin of Canadian Petroleum Geology, 45: 675-692.

Orchard, M.J. Zonneveld, J.P. Johns, M.J. McRoberts, C.A. Sandy, M.R., Tozer E.T. & Carrelli, G. G. 2001. Fossil succession and sequence stratigraphy of the Upper Triassic of Black Bear Ridge, northeast British Columbia, a GSSP prospect for the Carnian-Norian boundary. Albertiana 25:10-22.

Poty, E., Aretz, M. & Hance, L., 2014. Belgian substages as a basis for an international chronostratigraphic division of the Tournaisian and Viséan. Geological Magazine, 151: 229-243.

Rigo, M., Bertinelli, A., Concheri, G., Gattolin, G., Godfrey, L., Katz, M.E., Maron, M., Mietto, P., Muttoni, G., Sprovieri, M. & Stellin, F., 2016. The Pignola-Abriola section (southern Apennines, Italy): a new GSSP candidate for the base of the Rhaetian Stage. Lethaia, 49: 287-306.

Rigo, M., Mazza, M., Karádi, V. & Nicora, A., 2018. New Upper Triassic conodont biozonation of the Tethyan realm. In: Tanner, L. (eds) The Late Triassic World. Springer, Cham, p.189-235. doi.org/10.1007/978-3-319-68009-5_6

Roghi, G., 2004. Palynological investigations in the Carnian of the Cave del Predil area (Julian Alps, NE Italy). Review of Palaeobotany and Palynology, 132: 1-35.

Shevyrev, A.A., 2006. Triassic biochronology: state of the art and main problems. Stratigraphy and geological correlation, 14: .629-641.

Shi, Z., Jin, X., Preto, N., Rigo, M., Du, Y. & Han, L., 2019. The Carnian Pluvial Episode at Ma'antang, Jiangyou in Upper Yangtze Block, Southwestern China. Journal of the Geological Society, 176: 197-207.

Tong, J., Chu, D., Liang, L., Shu, W., Song, H., Song, T., Song, H. & Wu, Y., 2019. Triassic integrative stratigraphy and timescale of China. Science China Earth Sciences, 62: 189-222.

Tozer, E.T. 1994. Significance of Triassic stage boundaries defined in North America. In: Geux, J. & Baud, A., (eds). *Recent Developments on Triassic Stratigraphy*, Mémoires de Géologie (Lausanne), 22 : 155-170.

Yamashita, D., Kato, H., Onoue, T. & Suzuki, N., 2018. Integrated Upper Triassic conodont and radiolarian biostratigraphies of the Panthalassa Ocean. Paleontological Research, 22 : 167-197.