

PS The Impact of Recalibrating Palynological Zones to the Chronometric Timescale: Revised Stratigraphic Relationships in Australian Permian and Triassic Hydrocarbon-Bearing Basins*

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Abstract

High-precision radioisotopic dating using Chemical Abrasion-Isotope Dilution Thermal Ionisation Mass Spectrometry (CA-IDTIMS) has been undertaken to allow the recalibration of the numerical ages of Permian and Triassic spore-pollen palynozones. These changes have been significant, with some zonal boundaries in the Permian changing by as much as 6 million years, and some in the Triassic changing by more than twice as much. Most of the samples analysed have come from Eastern Australian coal basins (Sydney, Gunnedah, Bowen) where abundant ash beds are scattered through the coal-bearing successions. The recalibrations of these widely used palynozones have implications for the timing of stratigraphic events far beyond the basins whence the samples came. Our revised dates for the Permian and Triassic palynozones can now be applied to all Permian and Triassic basins across Australia, from the Perth, Carnarvon, Roebuck, Canning, and Bonaparte basins along the western and northern continental margins, the Cooper and Galilee basins in central Australia, and the Bowen, Gunnedah and Sydney basins in eastern Australia. Revised regional stratigraphic frameworks presented here include the Perth, Bonaparte, Cooper, Galilee and Sydney basins. The impact of an improved calibration of biostratigraphic zones to the numerical timescale is broad and far-reaching. For example, accurate stratigraphic ages are required for reliable burial history modelling, impacting on the prediction of kerogen maturation, hydrocarbon

expulsion and migration. Basin models that utilise these improved age interpretations will more closely approximate the true basin history. These improvements can in turn be expected to translate in to better exploration outcomes. So far, we have focused on the Permian and Triassic, but plan to expand recalibrations to include the Jurassic and Cretaceous successions. Preliminary data indicates that significant changes to these calibrations are also likely.

References Cited

Bodorkos, S., J. Crowley, E. Holmes, J. Laurie, D. Mantle, J. McKellar, A. Mory, R. Nicoll, L. Phillips, T. Smith, M. Stephenson, and G. Wood, 2016, New Dates for Permian Palynostratigraphic Biozones in the Sydney, Gunnedah, Bowen, Galilee and Canning Basins, Australia: *Permophiles*, v. 63, p. 19-21.

Bomfleur, B., R. Schöner, J.W. Schneider, L. Viereck, H. Kerp, and J.L. McKellar, 2014, From the Transantarctic Basin to the Ferrar Large Igneous Province – New Palynostratigraphic Age Constraints for Triassic-Jurassic Sedimentation and Magmatism in East Antarctica: Review of Palaeobotany and Palynology, v. 207, p. 18-37.

de Jersey, N.J., and M. Hamilton, 1965, Palynology of Samples from the Kingaroy Area: *Queensland Government Mining Journal*, v. 66, p. 74-76.

Hall, L.S., A. Hill, A. Troup, R. Korsch, B. Radke, R.S. Nicoll, T. Palu, L. Wang, and A. Stacey, 2015, Cooper Basin Architecture and Lithofacies: Regional Hydrocarbon Prospectivity of the Cooper Basin, Part 1: *Geoscience Australia Record*, 2015/31.

International Commission on Stratigraphy, 2017, International Chronostratigraphic Chart v2017/02. <http://www.stratigraphy.org/index.php/ics-chart-timescale>. Website accessed November 2017.

Laurie, J.R., S. Bodorkos, R.S. Nicoll, J.L. Crowley, D.J. Mantle, A.J. Mory, G.R. Wood, J. Backhouse, E.K. Holmes, T.E. Smith, and D.C. Champion, 2016, Calibrating the Middle and Late Permian Palynostratigraphy of Australia to the Geologic Time Scale Via U–Pb Zircon CA-IDTIMS Dating: *Australian Journal of Earth Sciences*, v. 63, p. 701-730.

Mantle, D.J., A.P. Kelman, R.S. Nicoll, and J.R. Laurie, 2010, Australian Biozonation Chart: Geoscience Australia, Canberra. https://d28rz98at9flks.cloudfront.net/70371/Australian_Biozonation_Chart_2010_Part1.pdf. Website accessed November 2017.

Mattinson, J.M., 2005, Zircon U-Pb Chemical Abrasion (“CA-TIMS”) Method: Combined Annealing and Multi-Step Partial Dissolution Analysis for Improved Precision and Accuracy of Zircon Ages: *Chemical Geology*, v. 220, p. 47-66.

Mundil, R., K.R. Ludwig, I. Metcalfe, and P.R. Renne, 2004, Age and Timing of the Permian Mass Extinctions: U/Pb Dating of Closed-System Zircons: *Science*, v. 305, p. 1760-1763.

Nicoll, R.S., J. McKellar, S.A. Ayaz, J.R. Laurie, J. Esterle, J. Crowley, G. Woods, and S. Bodorkos, 2015, CA-IDTIMS Dating of Tuffs: Calibration of Palynostratigraphy and Stratigraphy of the Bowen and Galilee Basins: Extended Abstract, 7th Bowen Basin Symposium, Brisbane, Queensland.

Nicoll, R.S., M. Bocking, T.E. Smith, J.L. Crowley, S. Bodorkos, E.K. Holmes, D. Mantle, and G.R. Wood, 2017, Dating of Marine Incursions and Unconformities in the Sydney and Gunnedah Basins of New South Wales Using U–Pb Zircon CA-IDTIMS Dating of Intercalated Tuffs: Extended Abstract, 40th Sydney Basin Symposium, Hunter Valley, New South Wales.

Price, P.L., 1997, Permian to Jurassic Palynostratigraphic Nomenclature of the Bowen and Surat Basins, *in* P.M. Green (ed.), The Surat and Bowen Basins, Southeast Queensland: Queensland Department of Mines and Energy, p. 137-178.

Retallack, G.J., N.D. Sheldon, P.F. Carr, M. Fanning, C.A. Thompson, M.L. Williams, B.G. Jones, and A. Hutton, 2011, Multiple Early Triassic Greenhouse Crises Impeded Recovery from Late Permian Mass Extinction: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 308, p. 233-251.

Smith, T.E., and D. Mantle, 2013, Late Permian Palynozones and Associated CA-IDTIMS Dated Tuffs from the Bowen Basin, Australia: Geoscience Australia Record 2013/46.

Smith, T.E., J. Ogg, A. Kelman, S. Abbott, and T. Bernecker, 2015, Toward Common Stratigraphic Frameworks for Australia's Offshore Hydrocarbon Provinces: Extended Abstract, APPEA Conference and Exhibition, 17-20 May 2015, Melbourne.



The impact of recalibrating palynological zones to the chronometric timescale: revised stratigraphic relationships in Australian Permian and Triassic hydrocarbon-bearing basins.

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Introduction

High-precision radiometric dating using Chemical Abrasion-Isotope Dilution Thermal Ionisation Mass Spectrometry (CA-IDTIMS) has allowed the recalibration of the numerical ages of Permian and Triassic spore-pollen palynozones in Australia. These changes have been significant, with some zonal boundaries in the Permian shifting by as much as six million years, and some in the Triassic by more than twice that. Most of the analysed samples came from eastern Australian coal basins (Sydney, Gunnedah, Bowen, Galilee) where abundant volcanic ash beds occur within the coal-bearing successions.

The recalibrations of these widely used palynozones have implications for the dating of geological events outside the basins from where samples were obtained. Our revised dates for the Permian palynozones can now be applied to all Permian basins across Australia, including the Perth, Carnarvon, Canning and Bonaparte basins (along the western and northern continental margins), the Cooper and Galilee basins (in central Australia), and the Bowen, Gunnedah and Sydney basins (in eastern Australia). Revised regional stratigraphic frameworks are presented here for these basins.

The impact of an improved calibration of biostratigraphic zones to the numerical timescale is broad and far-reaching. For example, the more accurate stratigraphic ages are the more closely burial history modelling will reflect the basin history, thereby providing control on the timing of kerogen maturation, and hydrocarbon expulsion and migration. These improvements can in turn be expected to translate in to improved exploration outcomes.

We have initially focused on the Permian and provide preliminary results for the Triassic, but intend to expand recalibrations to include Jurassic, Cretaceous and Paleozoic successions beyond the Permian. Preliminary data indicates that significant changes to these calibrations are also likely.

CA-IDTIMS dating of zircons from felsic tuffs

In eastern Australia, the Permian succession contains numerous felsic ash beds, many of which contain magmatic zircons constraining their eruptive ages. Volcanic ash beds are particularly prominent in coal-bearing strata (Figure 1) and represent time-surfaces within these successions. High-precision U–Pb dating of zircons from these units via CA-IDTIMS (Mattinson, 2005) has the potential to (1) greatly facilitate intra- and inter-basin correlations, and (2) contribute to numerical age-calibration of biozonation schemes, when the dated ash beds are biostratigraphically controlled.

The CA-IDTIMS technique involves pre-treating zircons via high-temperature thermal annealing, followed by partial dissolution and chemical abrasion using pressurised hot concentrated hydrofluoric acid (HF). This pre-treatment effectively removes zircon domains affected by post-crystallisation loss of radiogenic lead, which tend to yield apparent ages that are younger than the true crystallisation age. The variations in the dates obtained from zircons that have undergone different modes of treatment prior to analysis are shown in Figure 2.

These data, obtained from Mundil et al. (2004), come from the analysis of zircons from sample SH16 from Bed 18 of the Dalong Formation in Shangsi County, Guangxi, China and demonstrates the significant effect of lead loss on radiometric dates obtained from zircons. Zircons untreated prior to analysis all yielded dates between about 235 Ma and 220 Ma, significantly younger than that obtained by CA-IDTIMS (253.7 ± 0.2 Ma; Mundil et al., 2004).



Figure 1. Thin white tuff layers are easily recognisable in coal seams (image source: Nicoll et al., 2015).

Zircons that were subjected to mild HF leaching and zircons that were air-abraded prior to analysis show similar age-patterns: several analyses approximate the CA-IDTIMS age, but several others are dispersed, and yielded ages as young as c. 230 Ma. Of the zircons subjected to chemical abrasion, two gave older dates, while the remainder formed a coherent cluster, none of which were “from the young (Pb loss) side of the distributions” (Mundil et al., 2004, p. 1761). Analysis of leachates extracted from chemically abraded zircons yielded much younger dates, confirming that the leachates consisted mostly of the parts of the crystals that had suffered significant Pb loss. This demonstrates how effectively chemical abrasion mitigates Pb loss, in comparison with previous zircon preparation techniques.

CA-IDTIMS analysis destroys the target zircon crystals, but measures all of the extracted uranium and lead, which results in very precise age determinations relative to microbeam-based techniques that measure much smaller sample volumes. For example, Retallack et al. (2011) dated tuff-hosted zircons from the southern Sydney Basin by Sensitive High Resolution Ion Micro Probe (SHRIMP), and zircons from the SHRIMP mounts were analysed using the CA-IDTIMS technique. Results of both sets of analyses are given in Figure 3; these demonstrate the vastly improved precision of the latter method. The CA-IDTIMS results also appear to be more accurate: the samples are arranged in stratigraphic order in Figure 3, and the CA-IDTIMS results are self-consistent, whereas the SHRIMP results are not.

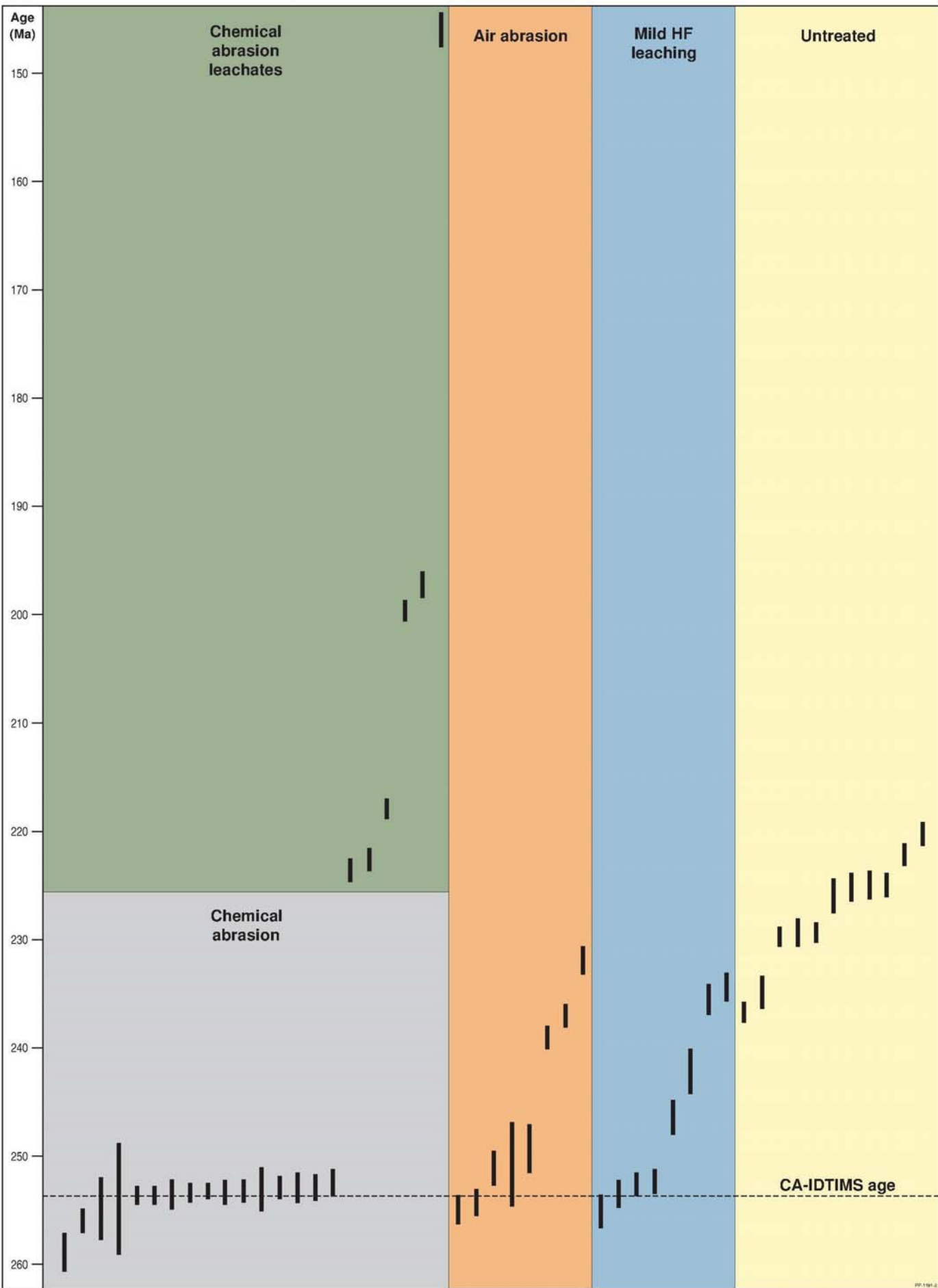


Figure 2. Dates obtained from a single ash bed (SH16 in Bed 18 of the Dalong Formation, Shangsi, China) using various treatment methods. From left to right, the samples have been prepared using chemical abrasion (grey), air abrasion (pink), and mild HF leaching (blue), while those on the right (yellow) were left untreated. The samples in the green field are the leachates obtained from chemically abraded zircons (data from Mundil et al., 2004, p. 1761, fig. 1).

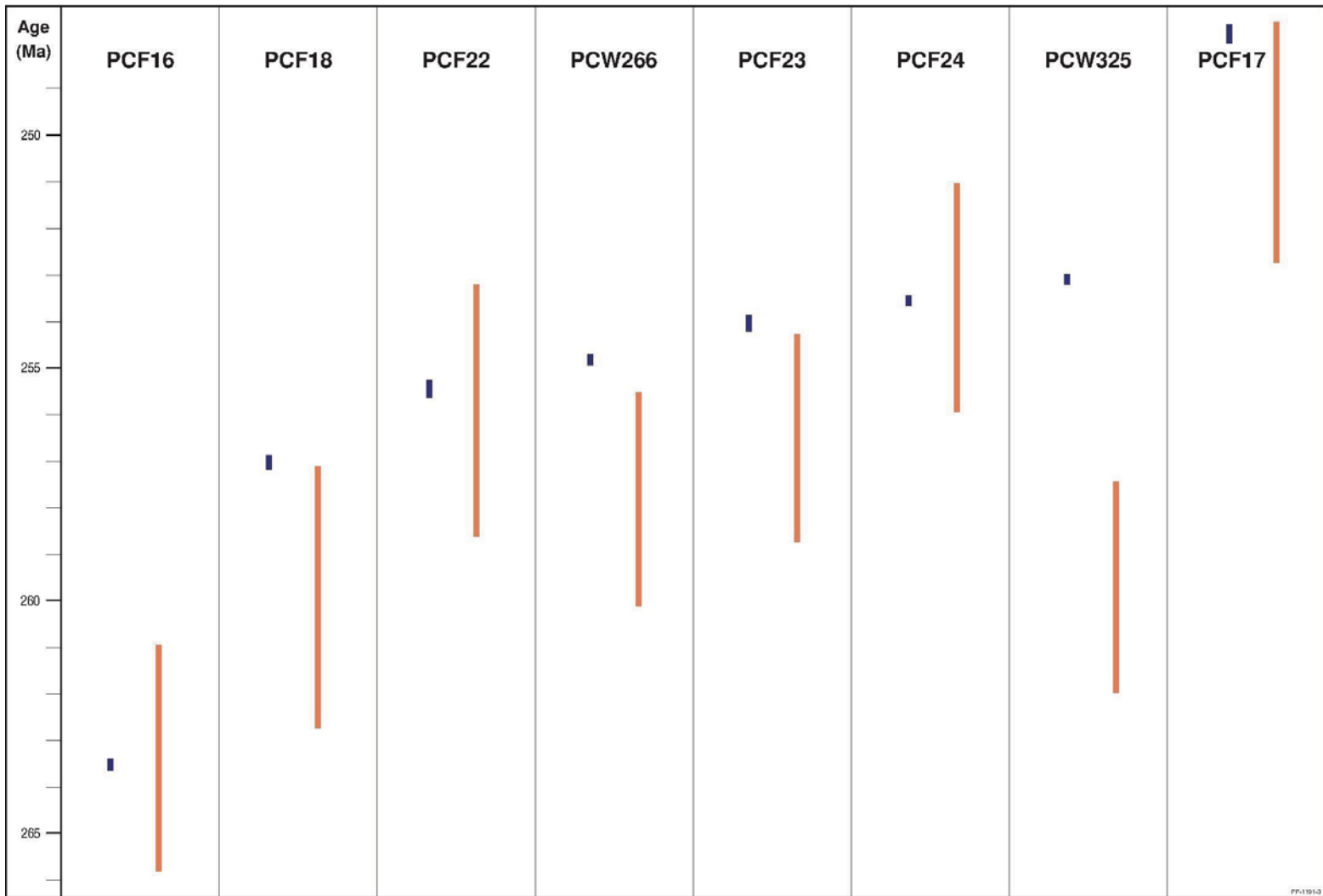


Figure 3. Comparison of SHRIMP dates (in red) used by Retallack et al. (2011) for various units in the Sydney Basin and CA-IDTIMS dates (in blue) obtained from zircons extracted from the same SHRIMP mounts. The errors in the Retallack et al. (2011) dates are 2σ , while those from the CA-IDTIMS dates are at 95% confidence intervals. The samples are in stratigraphic order, with the oldest at the left and the youngest at the right.

Recalibrating Permian palynostratigraphy

Early attempts to calibrate the Australian local palynostratigraphic scheme to the global timescale were indirect (Mantle et al., 2010), having traditionally relied on correlations from relatively sparse, high-latitude, marine strata, within which ammonoids and conodonts are rare, fusulinids are unknown, and much of the other fauna (brachiopods, bivalves) is endemic. To remedy this and provide direct tie-points, sampling of ash beds has been coupled with sampling of adjacent clastics for palynomorphs, mostly from drillcore and coalmines in the Bowen and Galilee basins (Queensland), Sydney and Gunnedah basins (New South Wales), and the Canning Basin (Western Australia). These locations are shown in Figure 4. Zircons from these ash beds have been subjected to the CA-IDTIMS technique for U–Pb dating. The resultant radioisotopic dates, with associated palynostratigraphic determinations, permit the direct calibration of the Mantle et al. (2010) scheme to the numerical timescale (Figure 5). Results shown in this figure for the Guadalupian and Lopingian have been previously published in Laurie et al. (2016). The Cisuralian data shown here are updated from those in Bodorkos et al. (2016), and the preparation of a publication on these, along with other results, is currently in progress.

The work so far conducted in the Cisuralian of Australia indicates that the APP3 (Price, 1997) zone is younger than previously calibrated and that the APP2 zone has a greater duration, starting earlier and ending later, than previously determined. The recalibrations indicate:

- the top of the *Pseudoreticulatispora confluens* (APP1.22) zone lies in the upper Asselian;
- the top of the *Pseudoreticulatispora pseudoreticulata* (APP2.1) zone lies in the middle Artinskian;
- the top of the *Microbaculispora trisina* (APP2.2) zone lies in the lower Kungurian; and
- the top of the *Phaselisporites cicatricosus* (APP3.1) zone lies in the upper Kungurian.

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

- the top of the *Praecolpatites sinuosus* (APP3.2) zone lies in the early Roadian;
- the top of the *Microbaculispora villosa* (APP3.3) zone lies in the middle Roadian;
- the top of the *Dulhuntyispora granulata* (APP4.1) zone lies in the Wordian;
- the top of the *Didecitriteles ericianus* (APP4.2) zone lies in the lower Wuchiapingian;
- the entire *Dulhuntyispora dulhuntyi* (APP4.3) zone lies within the Wuchiapingian; and
- the top of the *Dulhuntyispora parvithola* (APP5) zone lies at or near the Permian–Triassic boundary.

Figure 6 shows images of some of the index species for the eastern Australian Permian palynological scheme.

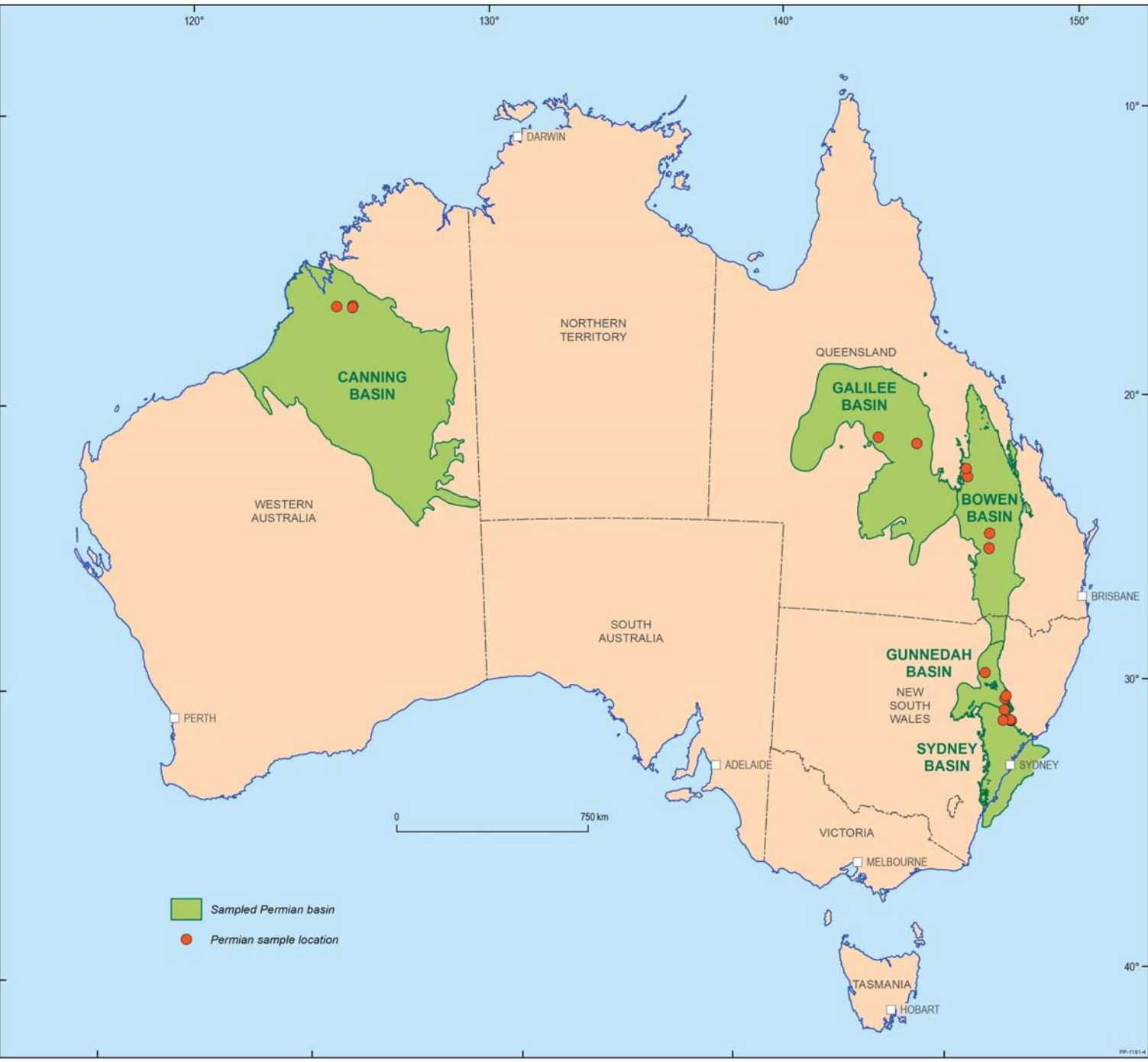


Figure 4. Map of Australia showing Permian sampling locations.

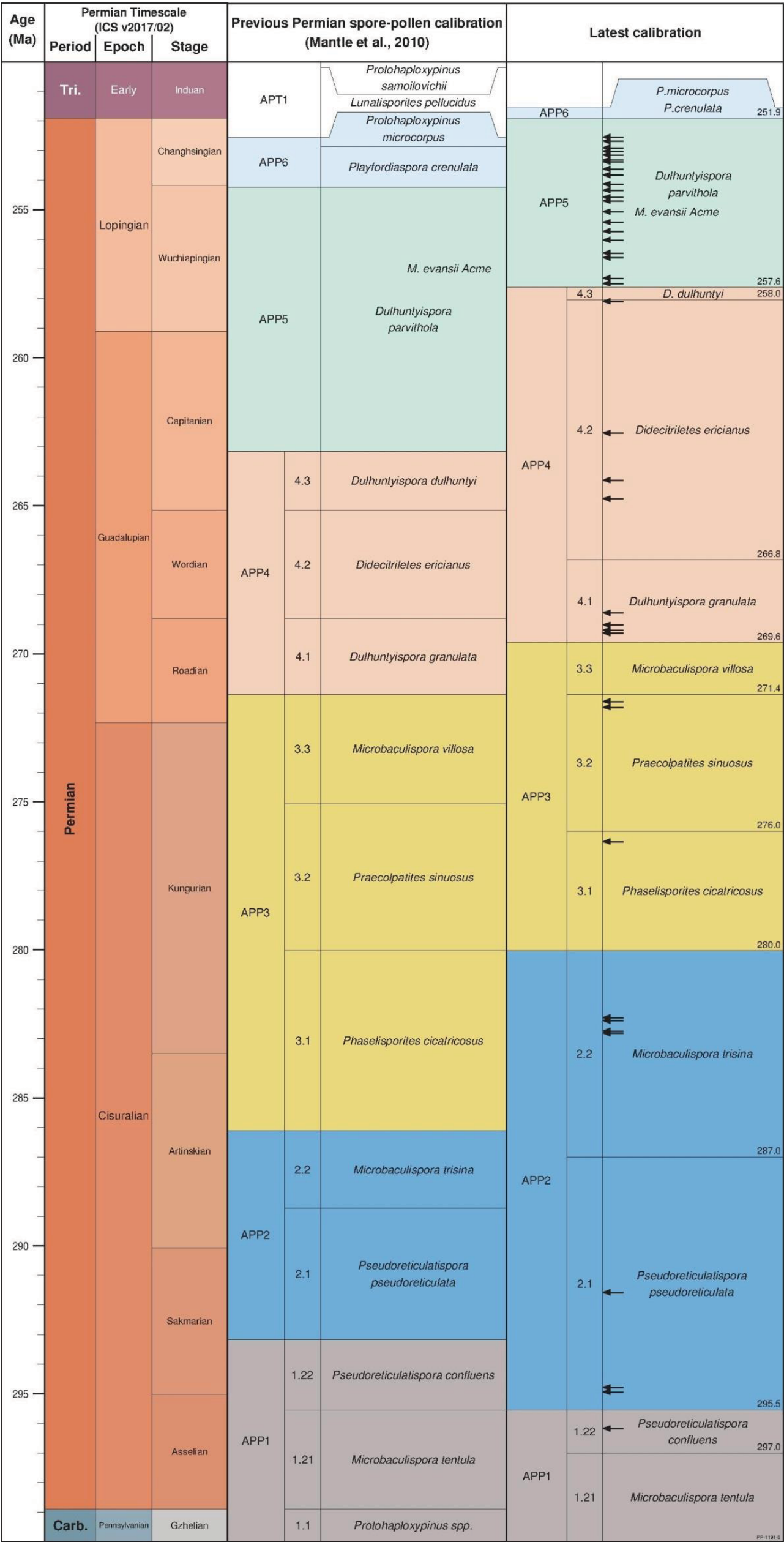


Figure 5. Revised calibration of Permian palynostratigraphy in Australia. Each arrow represents a biostratigraphically controlled U–Pb zircon date obtained via CA-IDTIMS and interpreted to represent the depositional age of the sampled tuff layer. Permian timescale from International Commission on Stratigraphy (2017).

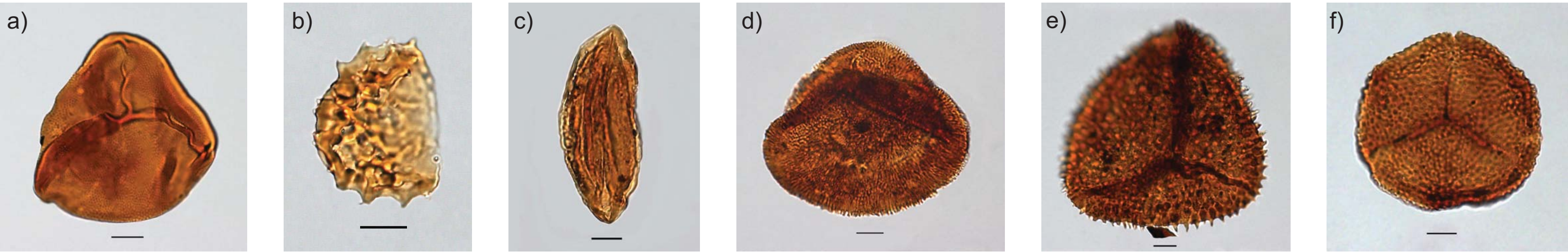


Figure 6. Images of some of the index species for the eastern Australian Permian palynological scheme. These are all from the APP5 zone in the Meeleebie 5 well from the Bowen Basin, Queensland, described in Smith & Mantle (2013): (a) *Microbaculispora trisina*; (b) *Phaselisporites cicatricosus*; (c) *Praecolpatites sinuosus*; (d) *Microbaculispora villosa*; (e) *Didecitriteles ericianus*; and (f) *Dulhuntyispora parvithola*. Scale bar is 10 microns.



Impacts on basin stratigraphy—some examples

Permian palynostratigraphic schemes are regularly used to provide age control on the deposition of lithological units in Australian basins. Revisions to biozone ages thus lead to revisions in stratigraphic ages. Petroleum systems modelling relies on accurate stratigraphic ages for generating burial history models for a basin, and a discrepancy of a few million years could mean the difference between immature or mature kerogen, or affect the pivotal timing of hydrocarbon expulsion and trap formation. It is important that petroleum explorers are aware of the latest and most accurately dated biozonation schemes, as models that utilise updated ages will reflect the most realistic basin history and potentially lead to improved exploration outcomes.

The impact that revised biozone ages can have on the age interpretations for local stratigraphic schemes can be substantial. Examples are shown here for the Permian succession of the Southern Coalfield (Sydney Basin) and the Cooper Basin. In each case, the current understanding of the basin stratigraphy is shown relative to the updated Permian palynological scheme presented here, then re-scaled to fit the preceding Mantle et al. (2010) scheme. This re-scaling highlights some of the significant impacts that using an outdated palynological scheme could have on interpretations of depositional ages and durations.

When the latest stratigraphy for the Southern Coalfield of the Sydney Basin (Nicoll et al., 2017) is re-scaled to the older Mantle et al. (2010) scheme, the stratigraphy is impacted significantly, in the order of millions of years (Figure 7). For example, the Sakmarian to Artinskian Clyde and Yarunga coal measures are currently assigned to the *Pseudoreticulatispora pseudoreticulata* palynozone. When re-scaled to the 2010 palynological scheme, this shortens their duration by almost half, changing from nearly 7 Myr to about 3.5 Myr. Conversely, the Illawarra Coal Measures, currently assigned entirely to within the Wuchiapingian and Changhsingian, have a much extended duration when re-scaled to the 2010 scheme, with the base dropping by more than 6 Myr, to fall within the Capitanian, and the top falling about 2 Myr to the uppermost Wuchiapingian. This results in a duration change from around 6 Myr to over 11 Myr for this economically important coal-bearing succession.

Similar impacts are observed when the latest Permian stratigraphy for the Cooper Basin is re-scaled to the older Mantle et al. (2010) scheme (Figure 8). For example, the Patchawarra Formation embraces the 2.1, 2.2, 3.1 and 3.2 biozones, spanning 21 Myr and most of the Cisuralian, from the lower Sakmarian to the upper Kungurian, when the current palynological scheme is employed. When re-scaled to the Mantle et al. (2010) scheme, the duration of the formation is reduced to 14 Myr, from the middle Sakmarian to the middle Kungurian. The top of the Murteree Shale is about 5 Myr older when re-scaled to the older scheme, and the APP5 Toolachee Formation almost doubles in duration, from about 5.5 Myr to over 10 Myr.

The impact on basin analysis and petroleum systems modelling can be significant depending which of these palynological schemes is applied. For example, most formations throughout the Permian succession of the Cooper Basin host source rocks, as well as unconventional gas occurrences, including basin-centred gas and tight gas accumulations, deep dry coal gas associated with the Patchawarra and Toolachee formations and the Murteree and Roseneath shale gas plays (Hall et al., 2015). Changes to the assigned ages of these units could have ramifications for the timing of kerogen maturation, hydrocarbon expulsion or migration.

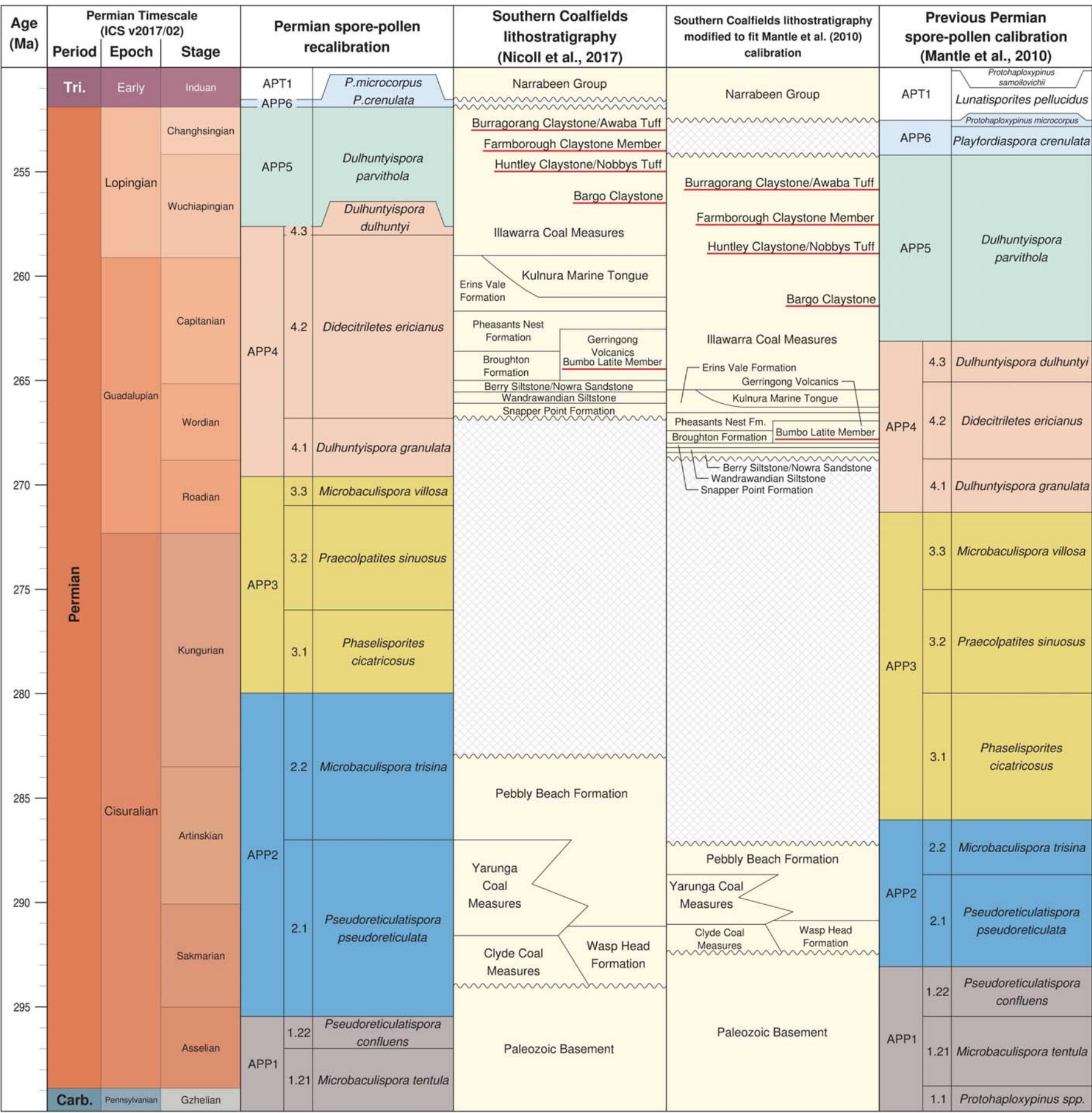


Figure 7. Stratigraphy of the Southern Coalfield, Sydney Basin, showing the potential impact of using poorly calibrated biozonation ages. The latest stratigraphic understanding of the coalfield is shown scaled against the recalibrated palynostratigraphy presented here, then re-scaled to the older Mantle et al. (2010) palynological scheme.

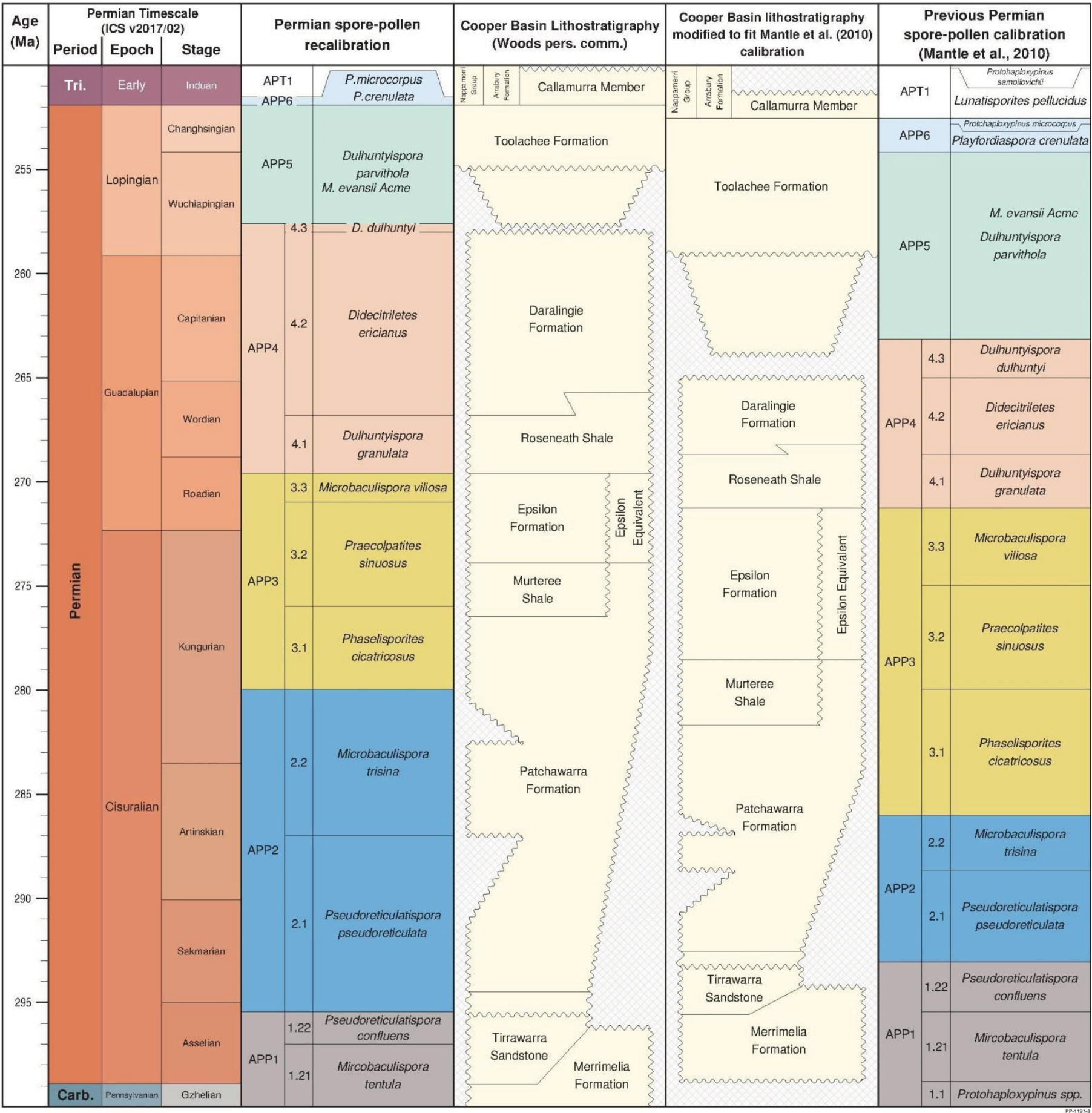


Figure 8. Stratigraphy of the Cooper Basin, showing the potential impact of using poorly calibrated biozonation ages. The latest stratigraphic understanding of the basin is shown scaled against the recalibrated palynostratigraphy presented here, then re-scaled to the older Mantle et al. (2010) palynological scheme.



Updated inter-basin correlations

The recalibrated Australian Permian palynological scheme is applied here to a number of basins across Australia (Figure 9), to provide comprehensive, up-to-date and accurate stratigraphic age control for many of the important hydrocarbon and coal-bearing basins across the continent. Revised chronostratigraphic correlations included here are for: Western Australia and the Northern Territory, from the northern Perth, Southern Carnarvon, Canning and southern Bonaparte basins (Figure 10); across South Australia and Queensland, for the Cooper, Galilee and Bowen basins (Figure 11); and, spanning much of New South Wales, for the Gunnedah Basin and the Sydney Basin coalfields (Figure 12).

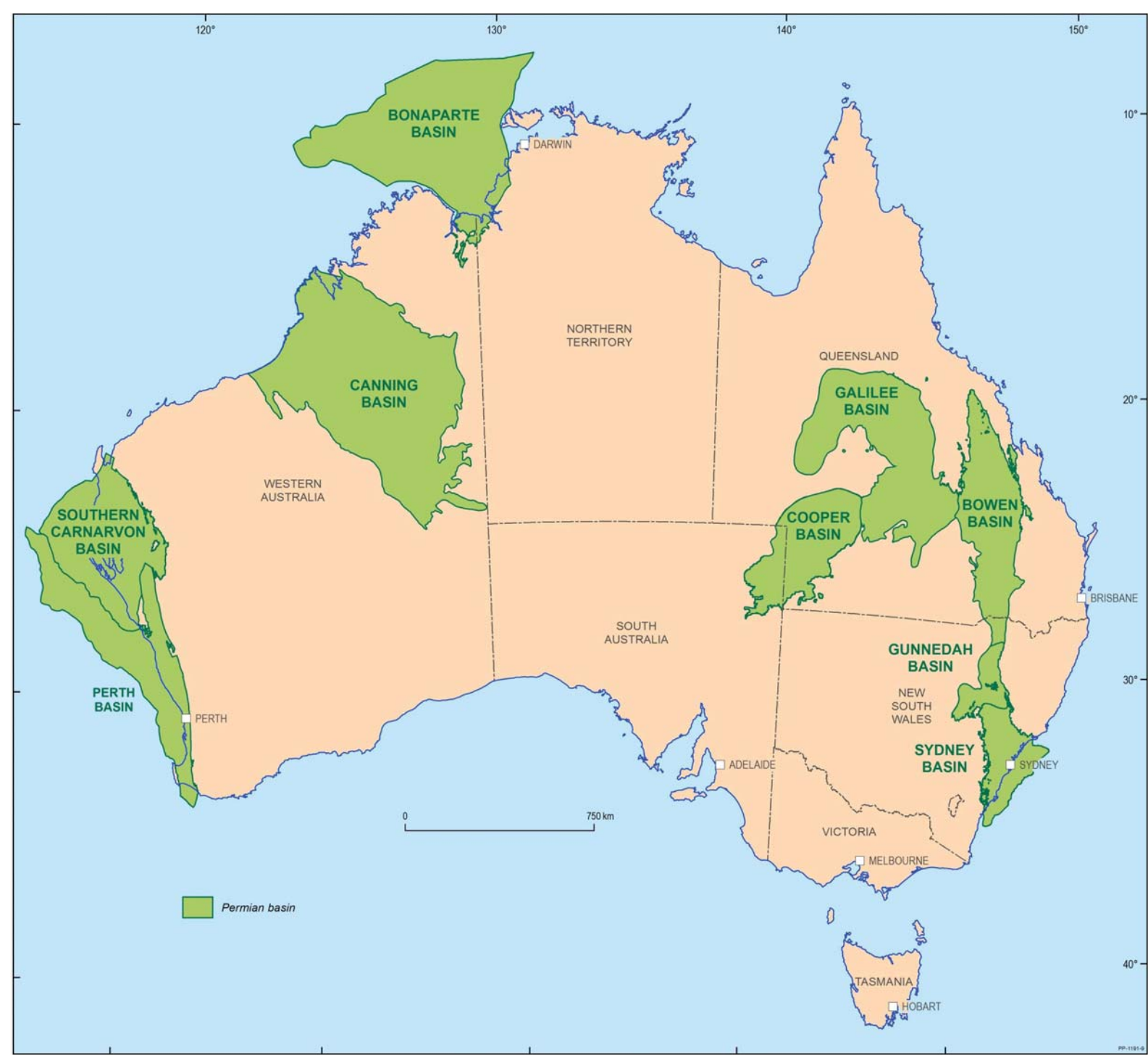


Figure 9. Map of Australia showing the locations of the nine basins included in these correlations.

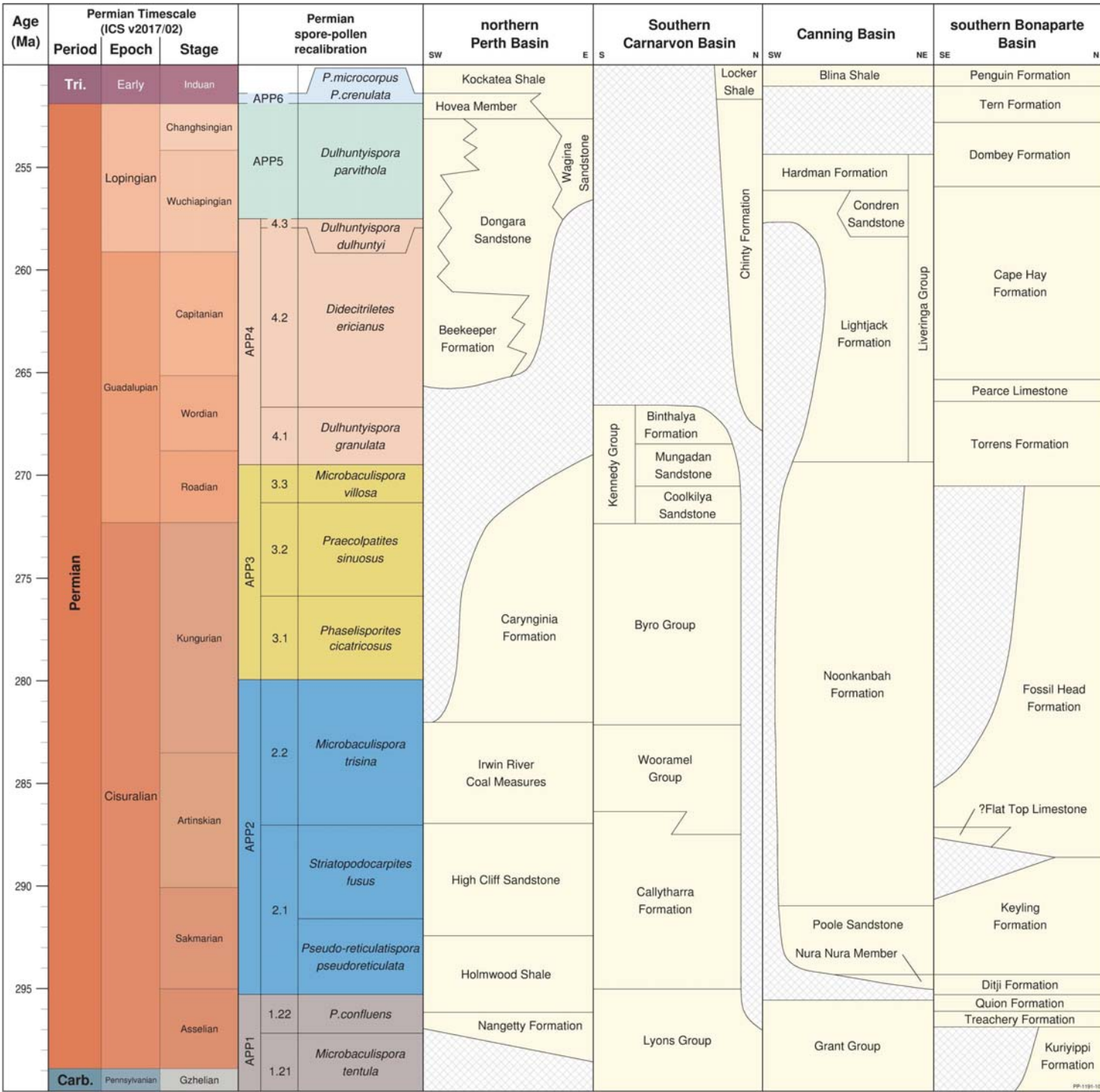


Figure 10. Chronostratigraphic correlation of the northern Perth, Southern Carnarvon, Canning and southern Bonaparte basins.

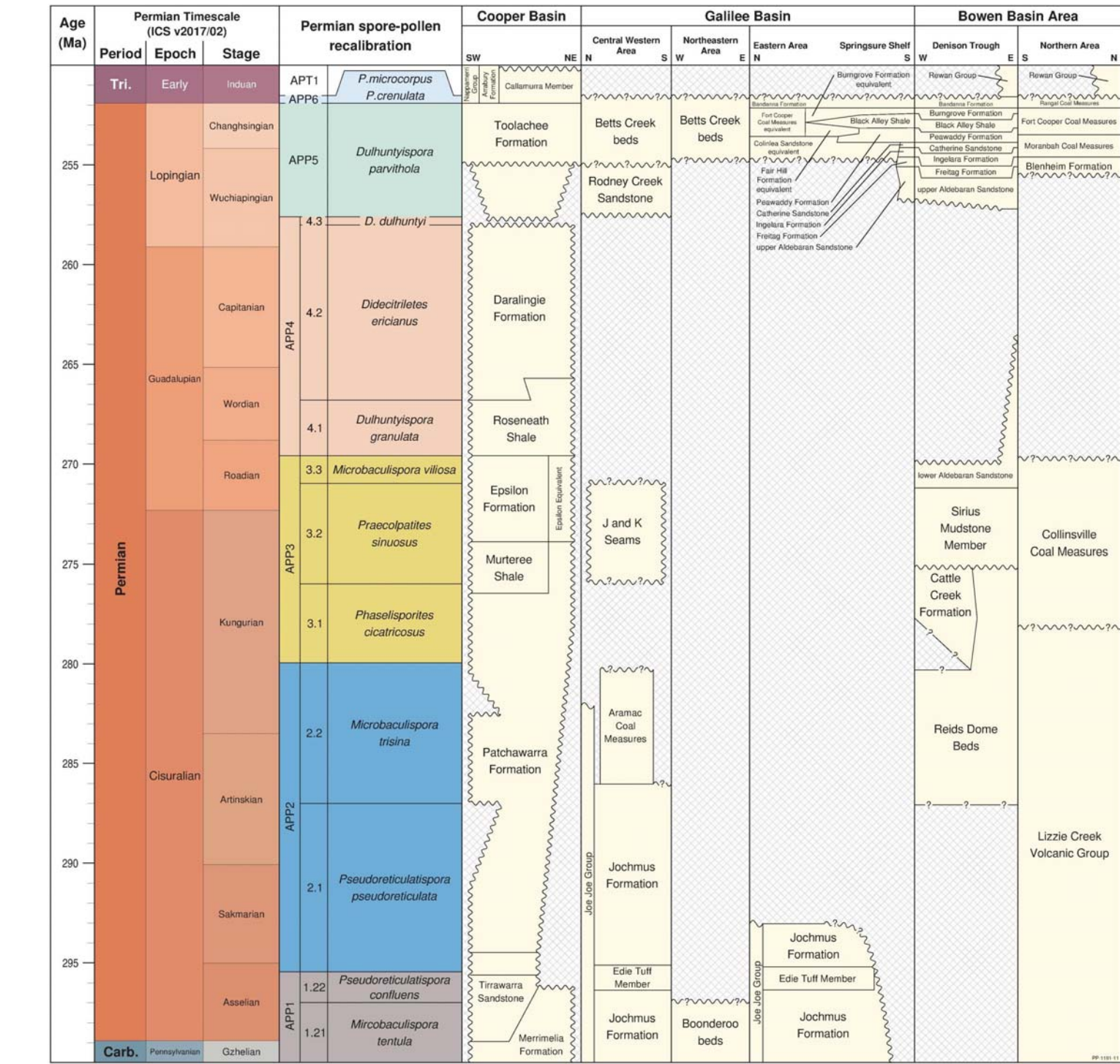


Figure 11. Chronostratigraphic correlation of the Cooper, Galilee and Bowen basins.

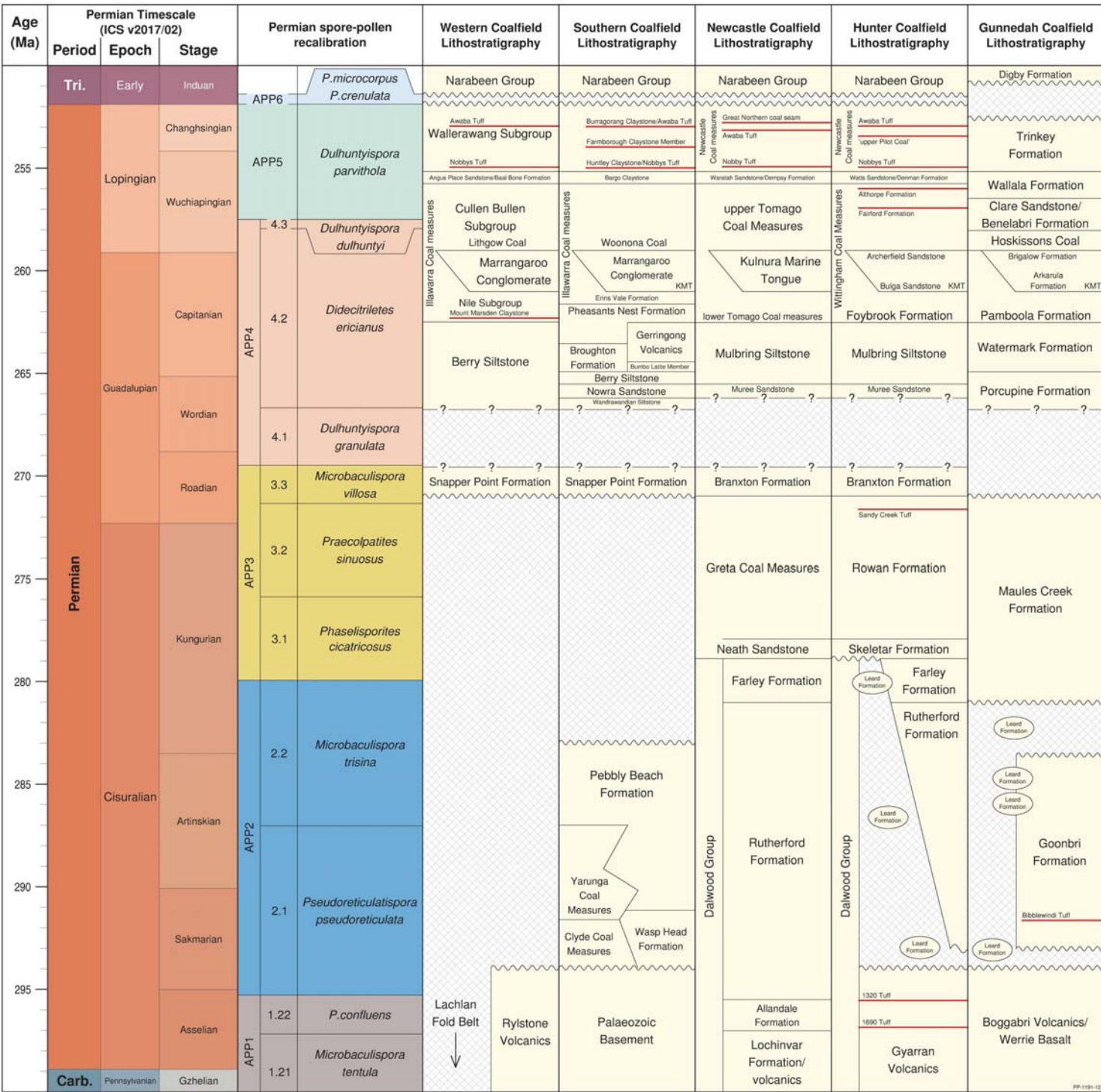


Figure 12. Chronostratigraphic correlation of the Western, Southern, Newcastle and Hunter coalfields of the Sydney Basin with the Gunnedah Basin.

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Preliminary Triassic biozonation recalibration

To date, seven CA-IDTIMS U–Pb zircon ages have been determined for Triassic biozones. The sampling locations for five of these samples, as well as other samples yet to be dated or awaiting biozonation determination, are shown in Figure 13. The other two dated samples were collected from Marokopa and Kiritehere in New Zealand. A preliminary recalibration of eastern Australian Triassic biozones based on the few preliminary dates is shown in Figure 14.

Most of the new dates corroborate the existing Triassic eastern Australian palynological scheme, as revised from Mantle et al. (2010), based on reinterpreted biozone ages from Geoscience Australia's 2014 North West Shelf Stratigraphy Workshop (Smith et al., 2015), plus modifications to the base of APT1 based on Laurie et al. (2016) and the division of APT5 from Bomfleur et al. (2014). Two dates, of 248.23 ± 0.13 Ma and 247.87 ± 0.14 Ma from the Garie Formation of the Sydney Basin (NSW) lie within the *Aratrisporites tenuispinosus* biozone. Two samples from the Upper Triassic Coal Measures of the Parmeener Supergroup (Tasmania) provide dates of 218.12 ± 0.08 Ma and 218.28 ± 0.06 Ma; both within the *Craterisporites rotundus* biozone. The two New Zealand samples, from the Arawi and Ngutunui formations, respectively provide dates of c. 210.0 Ma and c. 203.1 Ma. The associated palynology indicates that these samples respectively lie within the *Polycingulatisporites crenulatus* and *Foveosporites moretonensis* biozones, which is in accordance with the combined eastern Australian and New Zealand zonal units of Bomfleur et al. (2014).

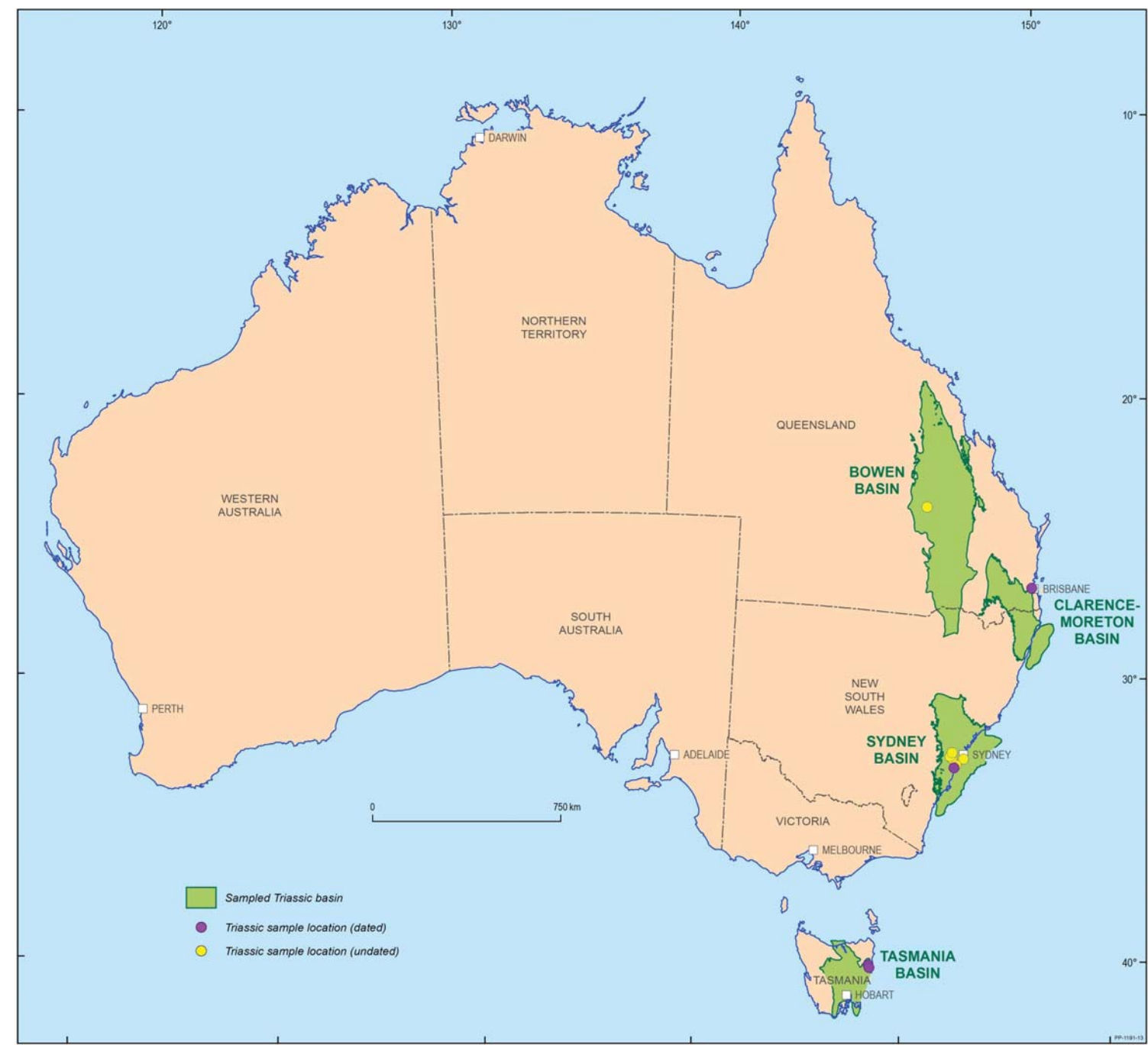


Figure 13. Map of Australia showing Triassic sampling locations. Blue circles are dated samples and red circles are not yet dated.

The remaining sample is from the Brisbane Tuff of the Clarence-Moreton Basin (Queensland). The Brisbane Tuff has been assigned to the *Craterisporites rotundus* biozone based on its proposed stratigraphic equivalence with the base of the Ipswich Coal Measures (de Jersey & Hamilton, 1965); however, the youngest dated zircons yielded a date of 227.08 ± 0.10 Ma, which is about 6 Myr older than the current calibration of the base of APT4. This result must be treated with caution, however, as zircon was sparse in the sample and several of the other dated grains yielded older ages, raising the possibility that all the dated grains are detrital in origin and thereby provide only a maximum age for eruption or deposition of the Brisbane Tuff.

A more comprehensive analysis of Triassic biozonation dating will be presented in detail at the Australasian Exploration Geoscience Conference in Sydney, Australia, in February 2018.

Conclusions

High-precision CA-IDTIMS U–Pb dating of zircons from tuff beds primarily sampled in the eastern Australian coal basins has facilitated a recalibration of Permian palynozones to the international timescale. This dating reveals that previous Permian biozonation schemes, largely calibrated through often tenuous correlations with Northern Hemisphere marine faunas, are often mis-calibrated to the numerical timescale. The age differences resulting from the Permian recalibration are on the order of millions of years and have impacts on the ages and durations of stratigraphic units for which palynozones provide age control. Updated chronostratigraphy is provided here for the Permian successions of numerous basins across Australia, with stratigraphic correlations through Western Australia to the Northern Territory, South Australia to Queensland and across New South Wales. A preliminary recalibration for Australian Triassic palynozones is also presented, with most of the new dates corroborating recent updates to the earlier eastern Australian spore-pollen scheme. Directly tying palynological schemes to the international timescale allows the use of the most up-to-date and accurate stratigraphic ages in petroleum systems models and in basin analysis more broadly. Improved age control leads to data sets that more accurately reflect the depositional history of a basin, and thus potentially leads to enhanced exploration outcomes.

References

Bodorkos, S., Crowley, J., Holmes, E., Laurie, J., Mantle, D., McKellar, J., Mory, A., Nicoll, R., Phillips, L., Smith, T., Stephenson, M. & Wood, G. 2016. New dates for Permian palynostratigraphic biozones in the Sydney, Gunnedah, Bowen, Galilee and Canning basins, Australia. *Permian* 63, 19–21.

Bomfleur, B., Schöner, R., Schneider, J.W., Viereck, L., Kerp, H. & McKellar, J.L. 2014. From the Transantarctic Basin to the Ferrar Large Igneous Province – New palynostratigraphic age constraints for Triassic–Jurassic sedimentation and magmatism in East Antarctica. *Review of Palaeobotany and Palynology* 207, 18–37.

de Jersey, N.J. & Hamilton, M. 1965. Palynology of samples from the Kingaroy area. *Queensland Government Mining Journal* 66, 74–76.

Hall, L.S., Hill, A., Troup, A., Korsch, R., Radke, B., Nicoll, R.S., Palu, T., Wang, L. & Stacey, A. 2015. Cooper Basin architecture and lithofacies: regional hydrocarbon prospectivity of the Cooper Basin, Part 1. Geoscience Australia Record 2015/31.

International Commission on Stratigraphy. 2017. International Chronostratigraphic Chart v2017/02. <http://www.stratigraphy.org/index.php/ics-chart-timescale>

Laurie, J.R., Bodorkos, S., Nicoll, R.S., Crowley, J.L., Mantle, D.J., Mory, A.J., Wood, G.R., Backhouse, J., Holmes, E.K., Smith, T.E. & Champion, D.C. 2016. Calibrating the middle and late Permian palynostratigraphy of Australia to the geologic time scale via U–Pb zircon CA-IDTIMS dating. *Australian Journal of Earth Sciences* 63, 701–730.

Mantle, D.J., Kelman, A.P., Nicoll, R.S. & Laurie, J.R. 2010. Australian Biozonation Chart. Geoscience Australia, Canberra. https://d28rz98at9fiks.cloudfront.net/70371/Australian_Biozonation_Chart_2010_Part1.pdf

Mattinson, J.M. 2005. Zircon U–Pb chemical abrasion (“CA-TIMS”) method: Combined annealing and multi-step partial dissolution analysis for improved precision and accuracy of zircon ages. *Chemical Geology* 220, 47–66.

Mundil, R., Ludwig, K.R., Metcalfe, I., & Renne, P.R. 2004. Age and timing of the Permian mass extinctions: U/Pb dating of closed-system zircons. *Science* 305, 1760–1763.

Nicoll, R.S., McKellar, J., Ayaz, S.A., Laurie, J.R., Esterle, J., Crowley, J., Woods, G. & Bodorkos, S. 2015. CA-IDTIMS dating of tuffs: calibration of palynostratigraphy and stratigraphy of the Bowen and Galilee basins. Extended abstract. 7th Bowen Basin Symposium, Brisbane, Queensland.

Nicoll, R.S., Bocking, M., Smith, T.E., Crowley, J.L., Bodorkos, S., Holmes, E.K., Mantle, D. & Wood, G.R. 2017. Dating of marine incursions and unconformities in the Sydney and Gunnedah basins of New South Wales using U–Pb zircon CA-IDTIMS dating of intercalated tuffs. Extended Abstract, 40th Sydney Basin Symposium. Hunter Valley, New South Wales.

Price, P. L. 1997. Permian to Jurassic palynostratigraphic nomenclature of the Bowen and Surat basins. In P. M. Green (Ed.), *The Surat and Bowen Basins, southeast Queensland*. Queensland Department of Mines and Energy. 137–178.

Retallack, G.J., Sheldon, N.D., Carr, P.F., Fanning, M., Thompson, C.A., Williams, M.L., Jones, B.G. & Hutton, A. 2011. Multiple Early Triassic greenhouse crises impeded recovery from Late Permian mass extinction. *Palaeogeography, Palaeoclimatology, Palaeoecology* 308, 233–251.

Smith, T.E. & Mantle, D. 2013. Late Permian palynozones and associated CA-IDTIMS dated tuffs from the Bowen Basin, Australia. Geoscience Australia Record 2013/46.

Smith, T.E., Ogg, J., Kelman, A., Abbott, S. & Bernecker, T. 2015. Toward common stratigraphic frameworks for Australia’s offshore hydrocarbon provinces. Extended Abstract, APPEA Conference and Exhibition, 17–20 May 2015, Melbourne.

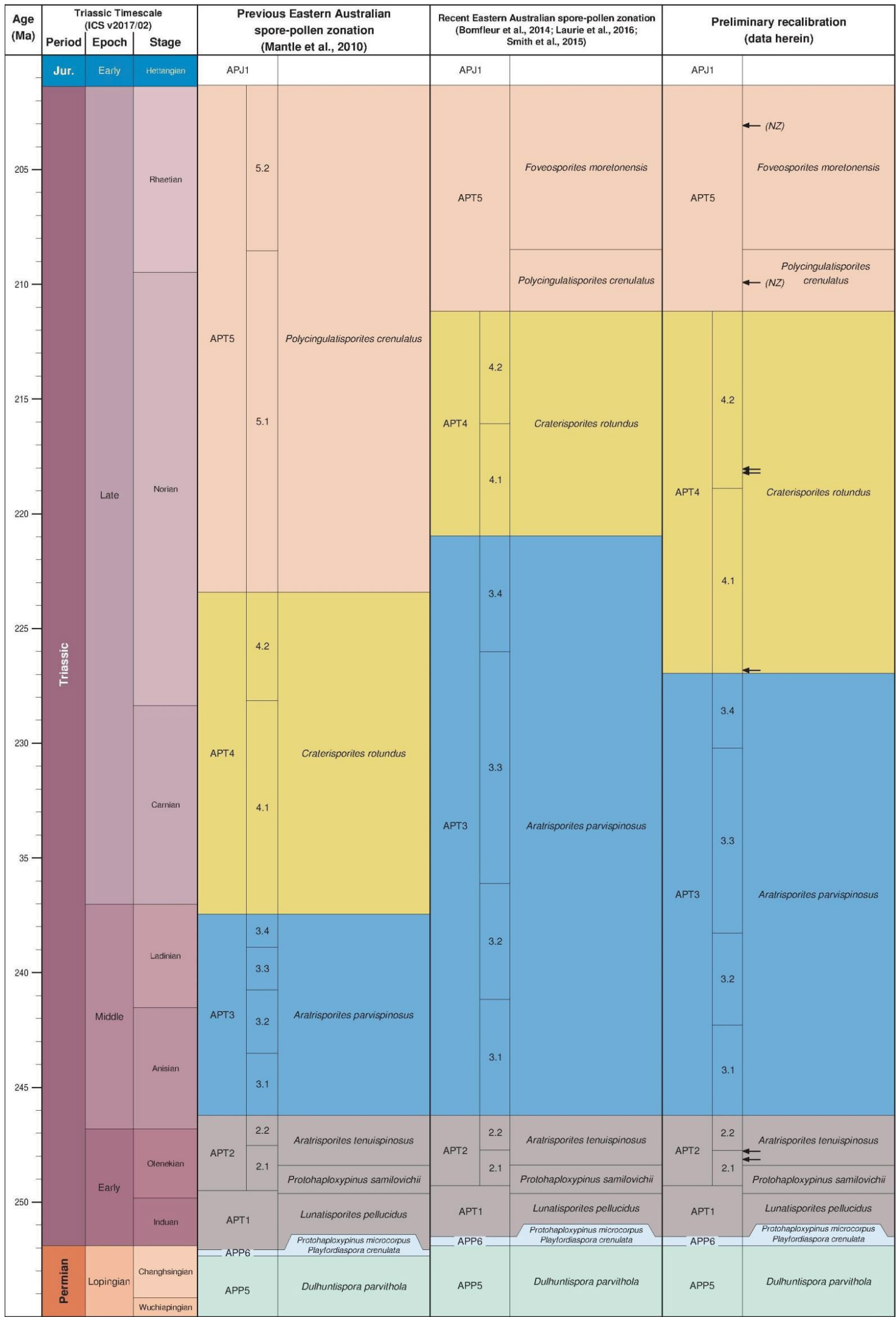


Figure 14. Preliminary revised calibration of Triassic palynostratigraphy in Australia. Each arrow represents a biostratigraphically controlled U–Pb zircon date obtained via CA-IDTIMS and interpreted to represent the depositional age of the sampled tuff layer. Triassic timescale from International Commission on Stratigraphy (2017).

