Rasmussen, C., Mundil, R., Irmis, R.B., Geisler, D., Gehrels, G.E., Olsen, P.E., Kent, D.V., Lepre, C., Kinney, S.T., Geissman, J.W., and Parker, W.G., 2020, U-Pb zircon geochronology and depositional age models for the Upper Triassic Chinle Formation (Petrified Forest National Park, Arizona, USA): Implications for Late Triassic paleoecological and paleoenvironmental change: GSA Bulletin, <https://doi.org/10.1130/B35485.1>.

Supplemental Material

Supplemental File 1. Assessing stratigraphic uncertainties between published dates and dates from CPCP 1A

Table S1. U-Pb zircon geochronology and depositional age models for the Upper Triassic Chinle Formation (Petrified Forest National Park, Arizona, USA): implications for Late Triassic paleoecological and paleoenvironmental change.

Table S2. U-Pb zircon geochronology and depositional age models for the Upper Triassic Chinle Formation (Petrified Forest National Park, Arizona, USA): implications for Late Triassic paleoecological and paleoenvironmental change

U-Pb zircon geochronology and depositional age models for the Upper Triassic Chinle Formation (Petrified Forest National Park, Arizona, USA): implications for Late Triassic paleoecological and paleoenvironmental change

Cornelia Rasmussen^{1,2†}, Roland Mundil³, Randall B. Irmis^{1,2}, Dominique Geisler⁴, George E. Gehrels⁴, Paul E. Olsen⁵, Dennis V. Kent^{5,6}, Christopher Lepre^{5,6}, Sean T. Kinney⁵, John W. Geissman⁷, and William G. Parker⁸

¹Department of Geology & Geophysics, University of Utah, Salt Lake City, UT 84112-0102, USA

²Natural History Museum of Utah, University of Utah, Salt Lake City, UT 84108-1214, USA

³Berkeley Geochronology Center, Berkeley, CA 94709

⁴Department of Geosciences, University of Arizona, Tucson, AZ 85721, USA

⁵Lamont-Doherty Earth Observatory, Columbia University, Palisades, NY 10964, USA

⁶Department of Earth and Planetary Sciences, Rutgers University, Piscataway, NJ 08854, USA

⁷Department of Geosciences, University of Texas at Dallas, Richardson, TX 75080, USA

⁸Division of Science and Resource Management, Petrified Forest National Park, Petrified Forest, AZ 86028, USA

†Corresponding author: crasmussen@utexas.edu; Current address: Institute for Geophysics and Department of Geological Sciences, Jackson School of Geosciences, University of Texas at Austin, Austin, TX 78758, USA

Supplemental File 1

Assessing stratigraphic uncertainties between published dates and dates from CPCP 1A

One of the driving motivations for coring at Petrified Forest was the uncertainty in placing outcrop data in a quantitatively accurate stratigraphic sequence (Olsen et al. 2018) when there was no reference section, a situation remedied by the CPCP core 1A. However, correlation of outcrop data to the core has uncertainties as well and are difficult to quantify. This is particularly true for the previously published zircon U-Pb data (Atchley et al. 2013; Ramezani et al. 2011, 2014; Nordt et al. 2015). Because of these uncertainties, it is difficult to compare these dates and our own. A large part of the uncertainty arises from questionable identification of marker beds shared between sections selected to produce composite sections especially between widely spaced sections; traditionally these marker beds are entirely fluvial sandstones which are very difficult to justify in a sedimentological processes sense. We can get some idea of the uncertainties by using linear correlation to project the outcrop locations of samples in published composites of different authors to the CPCP 1A core (Figure S1).

Kent et al. (2019), used linear regression between Atchley et al. (2013) [Appendix Fig 1; incorporating the dates of Ramezani et al. (2011)] and the CPCP 1A core, using unit boundaries as depicted by Atchley et al. (2013) and Olsen et al. (2018) as correlative tie points.

Figure S1: Outcrop sections of different authors with placement of samples that produced the dates in Ramezani et al. (2011), Atchley et al. (2013), and Nordt et al. (2015) correlated to the CPCP 1A core showing the uncertainties among the stratigraphic placement of outcrop samples relative to the core depending on the author of the sections and correlation fiducials employed.

However, the Atchley et al. (2013) column is a composite of three sections (northern park, southern park and Hunt Valley) each more than 20 km apart from the stratigraphically adjacent section. If instead, the base of the Blue Mesa Member is used as a datum, and the section are re-correlated it results in a shift of nearly ten meters down section of TPs, and SS-7 and smaller amounts for SBJ and GPL. A smaller adjustment occurs if the base of the Black Forest Bed is used to correlate as opposed to the base of the Owl Rock Member. Much larger changes in apparent position occur if the locations for Ramezani's (2011) samples are correlated to the Parker and

Martz (2011) northern and southern sections individually or in their composite section, using the base Blue Mesa and Black Forest Bed as fiducials. The largest discrepancy is generated by a difference of about 25 m in the stratigraphic position of the Jasper Forest Bed between Parker and Martz (2011) and Atchley et al. (2013). The Jasper Forest Bed produce sample GPL, resulting in a total stratigraphic uncertainty of more than 30 m, the provenance of which we have been able to conform. The entire section overlying Jasper Forest Bed the and all of its samples in the southern park section are correspondingly shifted down in Parker and Martz (2011) relative to Atchley, et al. (2013), resulting in similar large uncertainties. Furthermore, depending on how the northern and southern park sections are correlated, even the relative order of samples GPU, KWI, and P57-C change.

If these different linear projection of the outcrop samples are used as uncertainly limits, the apparent discrepancies between the Ramezani et al. (2011) dates and our new dates (Main Text Figure 3) disappear or nearly disappear into the stratigraphic uncertainty (Figure S1) (Main Text Figure 3). Only TPs remains irreconcilably too old compared to our data, including our oldest samples, and dating of recycled older grains is the only plausible explanation.

As already discussed in Olsen et al. (2018), the stratigraphic thickness of the members of the Chinle Formation in the CPCP core 1A are very similar to their inferred thickness in outcrop based on composites of individual correlated sections. Though the thickness of the lowest unit, the Mesa Redondo Member, cannot be compared because the base of the member does not crop out in the park, the overlying Blue Mesa Member in core CPCP 1A has a thickness of ~52 m, which matches well with the thicknesses of ~47-50 m reported by Atchley et al. (2013) and Martz et al. (2012). The Sonsela Member in CPCP 1A has a stratigraphic thickness of ~119 m, which is thicker than the ~88-90 m estimated from outcrop (Atchley et al., 2013; Martz et al. 2012). However, this difference is not surprising because this unit requires a long lateral traverse of ~5-10 km (e.g., Martz & Parker 2010: figs. 6-9) to estimate the complete Sonsela Member thickness from outcrop, resulting in increased uncertainty from sighting error. Additionally, there could be some true variation in unit thickness, as these outcrop estimates are from the southern portion of PFNP, whereas the core was drilled in the north, where the base of the Sonsela Member is not exposed (Parker and Martz, 2011: fig. 5; Martz et al., 2012; Martz and Parker, 2017: fig. 10). The discrepancy could also arise from the presence of an addition bed of sandstone in the core included by Olsen et al. (2018) in the Sonsela equivalent to more mudstone-dominated section in outcrop that would otherwise be part of the Petrified Forest Member. Finally, the overlying Petrified Forest Member again matches closely with outcrop estimates, with a stratigraphic thickness of ~119 m from core, and estimates of ~125-130 m from outcrop (Atchley et al., 2013; Martz et al., 2012). Even individual bed-level units are within error; the Black Forest bed is ~11 m thick in core CPCP 1A, and has been estimated at ~9-13 m thick in outcrop (Ash, 1992; Atchley et al., 2013; Martz et al., 2012). Therefore, the stratigraphic thicknesses of members as defined in the CPCP 1A core closely approximate the stratigraphic thicknesses estimated in outcrop; hence, it seems very

unlikely that core-outcrop lithostratigraphic miscorrelation is responsible for the discrepancy we observe between core and outcrop U-Pb ages in the lower half of the Chinle Formation.

References cited

- Ash, S., 1992, The Black Forest Bed, a distinctive unit in the Upper Triassic Chinle Formation, northeastern Arizona: *Journal of the Arizona-Nevada Academy of Science*, v. 24-25, p. 59-73.
- Atchley, S.C., Nordt, L.C., Dworkin, S.I., Ramezani, J., Parker, W.G., Ash, S.R., and Bowring, S.A., 2013, A linkage among Pangean tectonism, cyclic alluviation, climate change, and biologic turnover in the Late Triassic: the record from the Chinle Formation, southwestern United States: *Journal of Sedimentary Research*, v. 83, p. 1147-1161.
- Kent, D. V., P. E. Olsen, C. Lepre, C. Rasmussen, R. Mundil, G. E. Gehrels, D. Giesler, R. B. Irmis, J. W. Geissman, and W. G. Parker, 2019, Magnetostratigraphy of the Entire Chinle Formation (Norian Age) in a Scientific Drill Core From Petrified Forest National Park (Arizona, USA) and Implications for Regional and Global Correlations in the Late Triassic: *Geochemistry Geophysics Geosystems*, v. 20, p. 4654-4664.
- Martz, J.W., and Parker, W.G., 2017, Revised formulation of the Late Triassic land vertebrate "faunachrons" of western North America: recommendations for codifying nascent systems of vertebrate biochronology, in Zeigler, K. E., and Parker, W. G., eds., *Terrestrial Depositional Systems: Deciphering Complexities Through Multiple Stratigraphic Methods*: Amsterdam, Elsevier, p. 39-124.
- Martz, J.W., Raucci, J.J., Skinner, L., Parker, W.G., Blakey, R.C., and Umhoefer, P., 2012, *Geologic map of Petrified Forest National Park, Arizona*.
- Nordt, L., Atchley, S., and Dworkin, S., 2015, Collapse of the Late Triassic megamonsoon in western equatorial Pangea, present-day American Southwest: *Geological Society of America Bulletin*, v. 127, p. 1798-1815.
- Olsen, P.E., Geissman, J.W., Kent, D.V., Gehrels, G.E., Mundil, R., Irmis, R.B., Lepre, C., Rasmussen, C., Giesler, D., Parker, W.G., Zakharova, N., Kürschner, W.M., Miller, C., Baranyi, V., Schaller, M.F., Whiteside, J.H., Schnurrenberger, D., Noren, A., Brady Shannon, K., O'Grady, R., Colbert, M.W., Maisano, J., Edey, D., Kinney, S.T., Molina-Garza, R., Bachman, G.H., Sha, J., and the CPCD team: Colorado Plateau Coring Project, Phase I (CPCP-I): a continuously cored, globally exportable chronology of Triassic continental environmental change from western North America: *Scientific Drilling*, v. 24, p. 15-40.
- Parker, W.G., and Martz, J.W., 2011, The Late Triassic (Norian) Adamanian–Revueltian tetrapod faunal transition in the Chinle Formation of Petrified Forest National Park, Arizona: *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, v. 101, p. 231-260.

- Ramezani, J., Hoke, G.D., Fastovsky, D.E., Bowring, S.A., Therrien, F., Dworkin, S.I., Atchley, S.C., and Nordt, L.C., 2011, High-precision U-Pb zircon geochronology of the Late Triassic Chinle Formation, Petrified Forest National Park (Arizona, USA): temporal constraints on the early evolution of dinosaurs: Geological Society of America Bulletin, v. 123, p. 2142-2159.
- Ramezani, J., Fastovsky, D.E., and Bowring, S.A., 2014, Revised chronostratigraphy of the lower Chinle Formation strata in Arizona and New Mexico (USA): high-precision U-Pb geochronological constraints on the Late Triassic evolution of dinosaurs: American Journal of Science, v. 314, p. 981-1008.