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Interactive comment on "LA-ICPMS U-Pb geochronology of detrital zircon grains from the Coconino, Moenkopi, and Chinle Formations in the Petrified Forest National Park (Arizona)" *by* George Gehrels et al.

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This manuscript is part of a series of contributions from the Colorado Plateau Coring Project (CPCP), including Olsen et al. (2018), Kent et al. (2018), Kent et al. (2019) and Rasmussen et al. (in review), which aim to construct a chronostratigraphic model for the subsurface Chinle Fm. strata at the Petrified Forest National Park (PEFO), for which a high-resolution chronostratigraphic framework has already been established based on integrated outcrop stratigraphic and CA-ID-TIMS geochronologic works of Ramezani et al. (2011: RA'11) and Atchley et al. (2013: AT'13). Here I review the data

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and conclusions of the manuscript under two main categories of Stratigraphy and U-Pb geochronology.

Stratigraphy ...

The Chinle Fm. is a package of alluvial (flood-) plain and fluvial channel deposits characterizes by vertically repetitive and laterally discontinuous sedimentary facies. Within the geographic boundaries of PEFO, correlation of the Chinle Fm. outcrops has been aided by a number of known 'key beds' such as the Newspaper Rock bed, Rainbow Forest/Jasper Forest beds, Flattop Sandstone beds, Painted Desert Sandstone beds, Black Forest bed, etc. Whereas the CPCP contributions have explicitly stated or implicitly indicated a high degree of confidence in their core-outcrop correlations, the underlying evidence for such confidence have not been laid out. Since the coring began near the surface outcrops of the Black Forest bed, it is safe to assume that this marker horizon was reliably identified in the core. But there has been no mention of any of the key beds being intercepted in the core. The manuscripts describes from the core a reddish siliceous horizon (Lines 140-142) of presumed biostratigraphic significance (in the outcrop). Martz and Parker (2010) report at least 3 such 'silcrete' horizons from outcrops of the Sonsela Mbr (labeled red, orange and black silcrete beds), so it is not clear precisely which one was intercepted in the core.

To make the matter worse, the Moenkopi Fm., as well as the Mesa Redondo, Blue Mesa and parts of the Sonsela Mbr are all predominated by 'reddish mudstones and interbedded sandstones' (Section 2). These units tend to weather differently in the outcrop due to compositional differences (e.g., volcanic ash content) and produce distinct landscapes throughout the Colorado Plateau. But in the fresh core and without the aid of marker beds, it is not clear at all how their mutual boundaries can be recognized.

The manuscript suggests that the Shinarump Member (conglomerate) of the Chinle Formation is a lateral correlative of the finer-grained strata of the (entire) Mesa Redondo Member, implying that the presence of Mesa Redondo lithologies explains the absence of Shinarump conglomerate from the core. This view is not supported by previous detailed stratigraphic studies, the most relevant of which is Stewart et al. (1972). These workers described the stratigraphy of the basal Chine Fm. near St. John's, AZ (50 km SE of PEFO) as consisting of 5.1m of mottled strata, 10.2m of Shinarump Member and 25.8m of Mesa Redondo Member, clearly distinguishing between these units stratigraphically. In fact the basal Mesa Redondo Mbr in the Hunt Valley area (23 km SE of PEFO) consists of a >10m thick conglomerate that could conceivably correlate with Shinarump (RA'11), but the overlying ∼15m of the Mesa Redondo strata clearly overlie – and are thus younger than – the conglomerate, as demonstrated by the outcrop U-Pb geochronology of RA'11 and AT'13. Therefore, the total absence of the Shinarump/Mesa Redondo conglomerate (and other key horizons) from the core is alarming and puts into serious question the accuracy of stratigraphic orientation of the core.

Considering the above issues and based on the observation that the subsurface and outcrop geochronologies appear fairly consistent near the top of the core and begin to deviate at depth, reaching a maximum bias of >3 myr near the base of the Chinle Fm., the first-order suspicion should be that the core stratigraphy may not not accurate. Unless clearly identifiable bed or beds are intercepted, this inaccuracy is expected to increase with depth, consistent with the observation. To produce a meaningful age model, the manuscript needs to quantitatively assess the stratigraphic uncertainty in the core as a function of depth.

U-Pb Geochronology ...

Notwithstanding that the U-Pb geochronologic data of this study provide invaluable insights into the sedimentary provenance of the Triassic formations of the Colorado Plateau, their depositional age interpretations have been highly problematic. Although the manuscript touches upon the issue of Pb loss in the analyzed zircons, neither its severity nor its impact on depositional age interpretations have not been properly addressed.

It is claimed that the U concentrations (ppm) of the analyzed zircon can be used screen out analyses compromised by Pb loss. In particular, it is suggested that the U concentration of the youngest zircon compared to the average U concentration of the youngest cluster of analyses can determine whether or not the youngest date is an outlier. This relationship has never been proven and the data of this study actually indicate the opposite. Of the 3 samples from which the youngest analyzed zircon has come out Jurassic in age (92-2, 196-3 and 297-2), two have shown to have a significantly lower U content than the average of the youngest cluster (150 and 165 ppm, compared to 240 and 340 ppm, respectively), and the U content of the third one (502 ppm) overlaps with that of the youngest cluster (439 ppm) within the inaccuracy of U measurements (∼20%, footnote 10 of Table DR3).

The fact is that at present, no a priori indicator of Pb loss exists. Once one or more analyses from a samples are empirically shown to be compromised by Pb loss, the remainder of its analyses are likely to be compromised to varying degrees as well, and the extent of Pb loss cannot be in any meaningful way modelled by looking at U concentration or any other compositional parameter. The large inaccuracy of U and Th measurements by LA-ICPMS (∼20%) makes these parameters even less useful.

Most importantly, if the chemically abraded ID-TIMS analyses show unequivocal evidence of persistent Pb loss in at least some of the analyses, it would be only logical to conclude that the microbeam analyses of the same zircons will be compromised (even to a larger degree) by Pb loss, as well. There are several strong lines of evidence that suggest this can be the case here. First, initial outcrop CA-ID-TIMS zircon analyses from the upper Blue Mesa Mbr at PEFO (sample TPs) reported in RA'11 showed 2 outliers up to 3.3 myr younger than the cluster of 7 overlapping analyses used to calculate the weighted mean age of the sample. These analyses had been chemically abraded at 180°C for 12 hours. Once the leach intensity was increased to 210°C (for 12 hours), no such young outliers appeared in the remainder of the outcrop CA-ID-TIMS U-Pb data reported in RA'11, AT'13 or Ramezani et al. (2014). Second, 2 out 4

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CA-ID-TIMS zircon dates reported in Kent et al. (2018) from the CPCP core had visibly younger outliers (up to 4) excluded from age calculations due to insufficient treatment of Pb loss. Third, a comparison between the selected youngest LA-ICPMS zircon analyses and their corresponding CA-ID-TIMS dates in Rasmussen et al. (in review) illustrated in Appendix 2 points out to an even more pervasive Pb loss problem. Here the chemically abraded ID-TIMS analyses are systematically older than their untreated LA-ICPMS counterparts (Lines 585-586), but yet show a comparable data scatter, and a significant number of younger analyses have evidently been excluded in order to reach “preferred” CA-TIMS ages. For other examples of microbeam U-Pb geochronology leading to anomalously young age models due to Pb loss, the authors are referred to Wu et al. (2016) and Schmitz et al. (2019).

To summarize, the validity of depositional ages derived from U-Pb zircon analyses of tuffs (and tuffaceous sediments) in a fluvial depositional system such as the Chinle Fm., as outlined by RA’11, depends on a) the ability to produce accurate and statistically meaningful weighted mean 206Pb/238U dates from the youngest clusters of analyses without involvement of young outliers, b) achieving the desirable degree of analytical precision to produce mutually distinctive maximum depositional ages from closely spaced tuff beds, and c) the extent to which these maximum depositional ages follow the stratigraphic order. A review of the LA-ICPMS (and CA-ID-TIMS) zircon dates presented in this manuscript (Table DR3, Fig. 13 and Appendix2) demonstrates that the data in general do not meet the above criteria for a valid depositional age constraint. The only exception perhaps is a brief stratigraphic interval between the so-called lower and upper Sonsela Member (encompassing samples 201, 196 and 195) where the criteria b and c seem to have been met. Interestingly, this is the same interval where RA’11 originally identified a hiatus or a series hiatuses in the Sonsela Member based on outcrop U-Pb zircon geochronology and calculated average sediment accumulation rates pointing to a condensed section.

It is notable that the outcrop samples SS-28 (Mesa Redondo Member) and SBJ (lower

Sonsela Member) dated as part of the RA'11 and AT'13 geochronologic study were a clay-rich (altered) tuff and a tuffaceous (paste-like) fine siltstone, respectively. The former was in fact the closest dated sample to a true ash-fall tuff both in terms of petrography and zircon age distribution (no detrital outliers), as described in detail in RA'11 and its supplemental materials. Therefore, the notion that the apparent geochronologic discrepancies between the present study and those of the RA'11/AT'13 in the lower Chinle could have to do with detrital zircon input is not supported by evidence.

On a final note, the Heckert et al. (2009) abstract ID-TIMS date of 220.9 ± 0.6 Ma referred to in the manuscript as a "blue Mesa Mbr" age constraint (upside down triangle in Fig. 13) in support of their age model is from an isolated outcrop in New Mexico (not Arizona) with dubious cross-state lithostratigraphic correlations to PEFO (see Ramezani et al., 2014). Irmis et al. (2011) presented a significantly younger ID-TIMS date of 218.1 ± 0.7 Ma from the exact same bed in New Mexico, which has not been mentioned here. Neither can be used to support the PEFO age model of this manuscript because of correlation uncertainties.

A note about magnetostratigraphy ....

The subsurface magnetostratigraphic study of Kent et al. (2019) from PEFO has resulted in stratigraphic ages for the lower Sonsela, Blue Mesa, and Mesa Redondo members that are at odds with the outcrop U-Pb geochronology of RA'11 and At'13, as well as much of the lower Chinle subsurface geochronology presented in this manuscript. In particular, their magnetostratigraphic model does not recognize the mid-Sonsela interval of condensed stratigraphy (caused by depositional gap or gaps) identified by RA'11, resulting in an anomalously young, downhole age model. The main reason for this discrepancy appears to be that Kent et al. (2019) have chosen to correlate their Sonsela Mbr magnetostratigraphy to Chron E14 of the Newark-Hartford geomagnetic polarity time scale (~216-213 Ma) irrespective of the independent radioisotopic age data from that interval. Their magnetostratigraphic interpretation assumes that the PEFO core record is continuous to the point that every single Newark-Hartford

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GPTS chron has been preserved in the core. Neither the lithologic characteristics of the Sonsela Mbr (incised fluvial channel deposits including massive conglomerates with extra-basinal clasts forming laterally continuous erosional surfaces: Martz and Parker, 2010) nor the bulk of U-Pb geochronology from the lower Chinle Formation support the magnetostratigraphic interpretation of Kent et al. (2019).

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